MINISTRY OF EDUCATION AND TECHNICAL EDUCATION

وزارة التربية والتعليم والتعليم الفني

Chemistry

Egyptian Baccalaureate

2nd Year

Part One

11

SPRIX

D.M.RAZK موقع الدكتور محمد رزق معلم الكيمياء التعليمي

Chemistry

Egyptian Baccalaureate

2nd Year

Advised by
INTERNATIONAL BACCALAUREATE®

The International Baccalaureate™

has reviewed the pedagogical and assessment approaches underpinning this textbook.

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Ministry of Education and Technical Education

New Administrative Capital

Cairo, Egypt

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Introduction

Chemistry helps us understand the substances that make up our world, how they behave, and how they change. From the air we breathe and the materials we use to the medicines we take, the energy we produce, and the technologies that shape modern life, chemistry is part of almost everything around us.

This Grade 11 Chemistry textbook has been developed in alignment with the vision of the Egyptian Baccalaureate System to provide students with a rigorous, engaging, and meaningful learning experience. It is designed not only to build scientific knowledge, but also to develop the ability to question, investigate, analyze evidence, solve problems, and apply learning in new and unfamiliar situations.

Throughout this course, you will explore two major areas of chemistry: States of Matter and Change and Equilibrium of Matter. You will investigate how matter changes from one state to another, how gases behave, how solutions and crystals are structured, and how physical properties can be explained using scientific principles and models. You will also examine chemical reactions, energy changes, electrochemical cells, electrolysis, reaction rates, chemical equilibrium, ionization, aqueous solutions, and solubility.

These topics are closely connected. Understanding the behavior of gases and solutions, for example, helps explain many natural and industrial processes. Studying enthalpy allows us to understand the energy involved in chemical reactions. Electrochemistry connects chemical change with the production and use of electrical energy, while reaction rates and equilibrium help explain why reactions occur as they do and how their conditions can be controlled.
Each lesson is designed to take you through a clear learning journey. You will begin by connecting new ideas to prior knowledge, familiar observations, or real-world phenomena. You will then explore scientific concepts through questions, examples, investigations, models, data, and problem-solving activities. As your understanding develops, you will have opportunities to practise what you have learned and apply it independently.

Chemistry is not learned through memorization alone. Throughout this textbook, you will be asked to observe carefully, identify patterns, interpret evidence, make predictions, construct explanations, perform calculations, and justify your conclusions. Practical investigations and scientific reasoning will help you understand not only what happens during a chemical or physical process, but also why it happens.

The textbook also develops essential scientific skills, including measurement, classification, prediction, inference, experimentation, data interpretation, modelling, problem-solving, and scientific communication. These skills will help you approach questions in the way scientists do: by examining evidence, testing ideas, evaluating explanations, and refining conclusions. Assessment is integrated throughout the learning process. Questions and activities will allow you to check your understanding, practise key concepts, and prepare for more demanding applications of knowledge. You will encounter tasks that require recall and understanding, but also analysis, reasoning, calculation, interpretation, and the application of chemistry to unfamiliar situations. Where appropriate, the course connects chemistry to real-world contexts such as energy, industry, health, technology, materials, and environmental sustainability. These applications show how chemical knowledge contributes to solving practical problems and addressing challenges faced by communities in Egypt and around the world.

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You will also be encouraged to think about the Nature of Science: how scientific knowledge is developed, tested, communicated, and refined over time. Scientific ideas do not emerge in isolation. They are built through observation, experimentation, evidence, debate, and the contributions of scientists across different cultures and generations.

Most importantly, this textbook is designed to help you become an active participant in your own learning. You will be encouraged to ask questions, reflect on your understanding, learn from mistakes, and make connections between different ideas. The aim is not simply to prepare you for an examination, but to develop the scientific knowledge, habits of mind, and confidence needed for future study and for life in an increasingly scientific and technological world.

As you begin this journey, approach chemistry with curiosity. Look beyond equations and definitions to the ideas they represent. Ask why substances behave as they do, examine the evidence carefully, and use what you learn to make sense of the world around you.
Chemistry is the study of matter and change, but learning chemistry can also change the way you see the world.

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How to use this book

Every lesson follows a scientific learning journey:
Observe ▪ Question ▪ Investigate ▪ Explain ▪ Apply ▪ Evaluate

1 **Guiding Question**
Each lesson begins with a guiding question that focuses your thinking and helps you connect chemistry to real-world phenomena.

2 **Engaging Introduction**
A short scenario, phenomenon, or authentic context introduces the lesson and demonstrates why the topic matters in everyday life, technology, and society.

3 **Point!**
Key concepts, definitions, laws, principles, and scientific models are presented clearly and systematically.

4 **Exploration**
Investigate patterns, analyze evidence, identify relationships, and make predictions before formal explanations are introduced.

5 **Warm Up**
Questions and Examples that help you in applying knowledge and prepare for deeper learning.

6 **Explanation**
Step-by-step explanations demonstrate scientific reasoning, calculations, and problem-solving strategies.

7 **Think Like a Chemist**
Apply scientific thinking to justify conclusions, evaluate claims, and interpret experimental results.

8 **Think as an Engineer**
Use chemistry concepts to solve practical problems and make evidence-based decisions in technological and engineering contexts.

9 **Life Application**
Discover how chemistry influences sustainability, health, energy production, industry, transportation, and everyday life.

10 **Structure of Science**
Explore the scientific concepts, models, and principles that connect the lesson to broader scientific understanding.

11 **Nature of Science**
Examine how scientists collect evidence, design investigations, evaluate data, and build reliable explanations.

12 **Misconceptions Alert**
Identify frequent mistakes and misconceptions so that your understanding becomes more accurate and scientifically sound.

13 **Key equations at a glance**
Important formulas, symbols, and relationships are summarized for quick reference.

14 **Try**
Practice your learning
Apply new concepts through guided questions and structured exercises.

15 **Exercise**
Strengthen your understanding through increasingly challenging questions that require reasoning, calculations, and analysis.

16 **Challenge Your Thinking**
Tackle higher-order questions that require evaluation, synthesis, problem-solving, and scientific argumentation.

17 **Reflect and Grow**
Revisit key concepts from current and previous lessons to strengthen long-term understanding and exam readiness.

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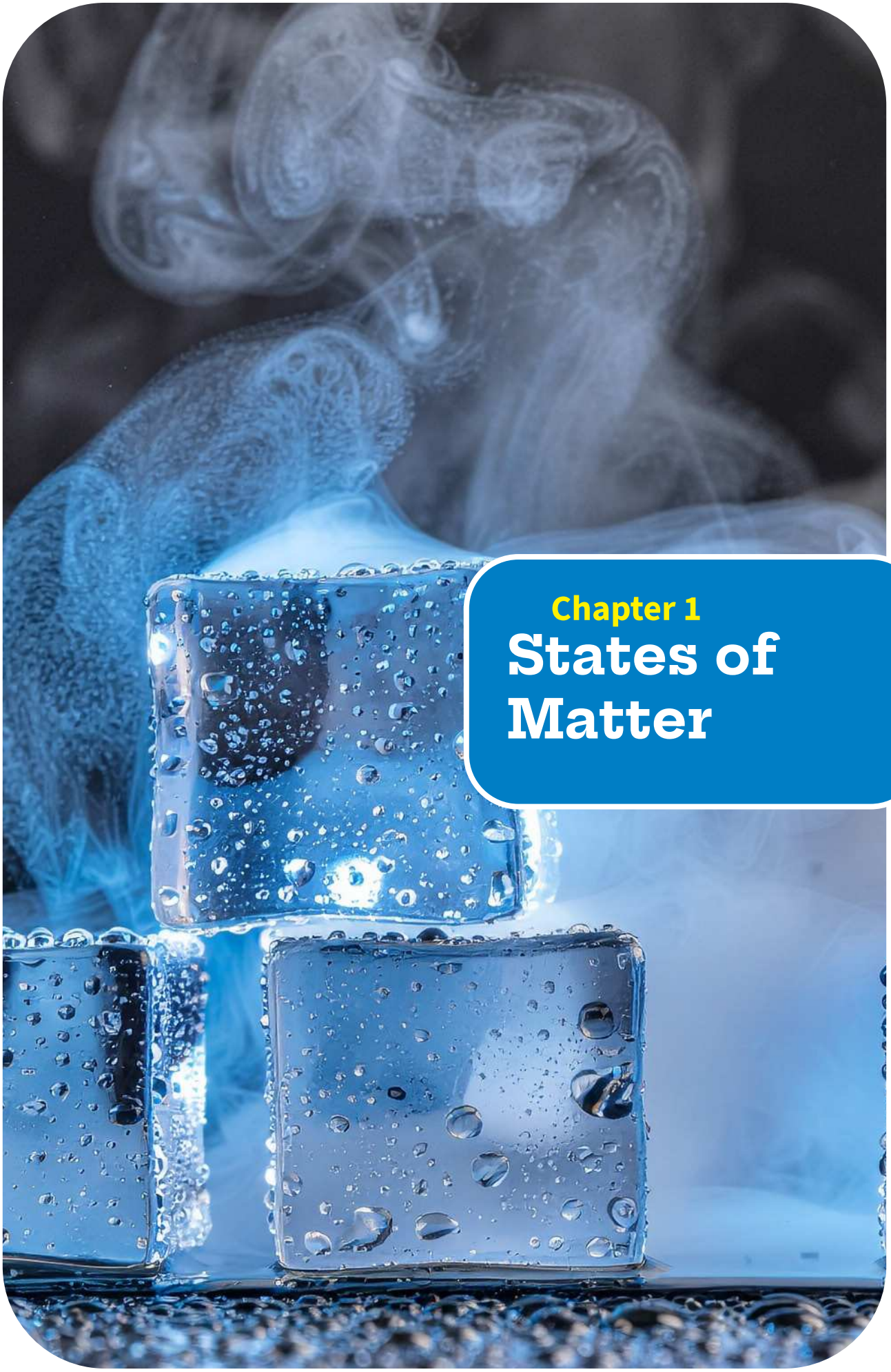

Chapter 1

States of Matter

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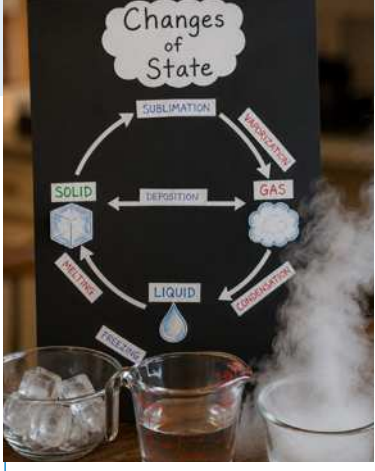


1-1 — Changes of State

✨ Engaging Introduction

Every day, matter changes around us in fascinating ways. Ice melts into water, puddles disappear after rain, and clouds form high in the sky. Although these changes seem simple, they are driven by the movement of particles and the transfer of energy.

In this lesson, you will explore how and why substances change their state, investigate the forces acting between particles, and discover how these ideas help explain natural phenomena that shape our world.

❓ **Guiding question**: How does energy shape the states of matter around us?

📌 **Point!**

1. Celsius Temperature and Absolute Temperature

(a) **Celsius temperature:** the temperature scale used in everyday life, measured in degrees Celsius (symbol: °C).

(b) **Absolute temperature:** a temperature scale that starts at absolute zero (−273 °C) and uses the same interval size as the Celsius scale. The unit is the kelvin (symbol: K).

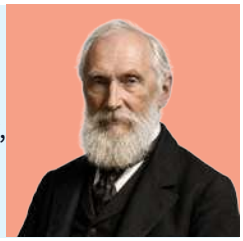
- The relationship between absolute temperature T (K) and Celsius temperature t (°C) is: $T = t + 273$.

Equation box

Relation	Expression	Note
Absolute ↔ Celsius temperature	T (K) = t (°C) + 273	Same interval size; the zero point differs by 273

🏅 Appreciating Scientists

The Kelvin scale is named after Lord Kelvin, whose work helped scientists understand the relationship between temperature, energy, and particle motion. Today, the Kelvin scale is used worldwide in chemistry, physics, and space science.



2. Changes of State

(a) A substance can change between the solid, liquid, and gas states through melting, boiling, condensation, and freezing.

(b) Changes of state (see Figure 1.1.1):

(i) **Heat of fusion:** the amount of heat required to change 1 mol of a solid into a liquid.

(ii) **Heat of vaporization:** the amount of heat required to change 1 mol of a liquid into a gas.

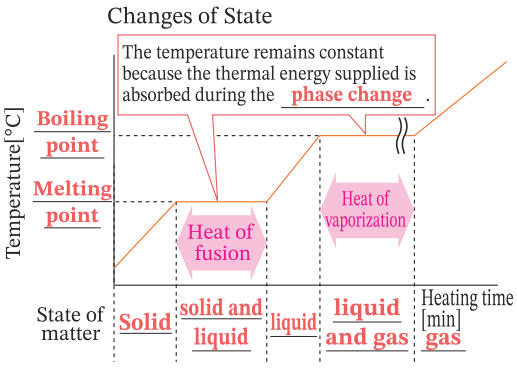


Figure 1.1.1. Relationship between temperature change and state of matter

(c) How to calculate the amount of heat

(i) Amount of heat in changes of state: Heat of fusion and heat of vaporization are expressed in kilojoules per mole [kJ/mol] measured at 1 atm pressure.

🌟 Structure of Science

Key Fact :

Changes of state and melting/boiling points depend on energy transfer and the strength of attractive forces between particles.

Key Concepts:

- Celsius temperature
- Absolute temperature
- Heat of fusion
- Heat of vaporization
- Van der Waals forces
- Hydrogen bond

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Example — calculate the amount of heat required to melt *36 g* of ice at *0 °C*. (Given: heat of fusion of water = *6.0 kJ/mol; molar mass of H_2O = 18 g/mol.)*
The Solution: 36 g of ice = 36 g ÷ 18 g/mol = 2.0 mol. Therefore the heat is *6.0 [kJ/mol] × 2.0 (mol) = 12 kJ*.

(ii) **Amount of heat in temperature changes:** Amount of heat in temperature changes: The specific heat capacity of water is 4.2 J/(g·°C) — that is, 4.2 J of heat is required to raise the temperature of 1 g of water by 1°C.

Example — The amount of heat required to heat 100 g of water from *5 °C to 25 °C is*
4.2 [J/(g·°C)] × 100 (g) × [25 − 5] [°C] = 8400 J = 8.4 kJ. $Q=m.\ c.\ (t_2-t_1)$

Think as an Engineer

You are designing a cooling system for transporting vaccines to remote communities. Which property would be more important when selecting a cooling substance?

□ High heat of fusion □ High heat of vaporization

Give evidence on your answer

_____

_____

3. Forces between Particles and Melting / Boiling Points

(a) **Intermolecular forces:** attractive forces acting between molecules. They are **weaker** than covalent bonds, ionic bonds, and metallic bonds.

(i) **Van der Waals forces:** weak attractive forces between molecules. The greater the relative molecular mass, the **stronger** they are. For molecules of similar relative molecular mass, the forces between polar molecules are **stronger** than those between non-polar molecules.

(ii) **Hydrogen** bond: a bond formed between two highly electronegative atoms (F, O, N) via a hydrogen atom that is covalently bonded to one of them. Hydrogen bonds are stronger than Van der Waals forces.

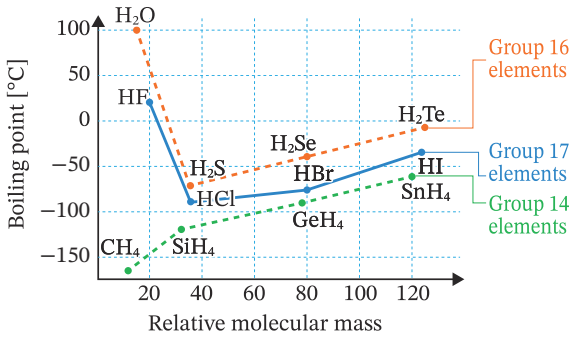

Fig 1.1.2. the boiling point curve

(b) **Forces between particles and melting / boiling points:** the stronger the attractive forces between the constituent particles, the higher the melting point and boiling point.

Example — For the boiling points of the substances shown in the figure 1.1.2 on the right:

Because **hydrogen** bonds form between the molecules, $H_2O > H_2S$. ·
Because it has a larger relative molecular mass, HBr > HCl. ·
Because the hydrides of Group 14 elements are non-polar molecules, they have low boiling points.

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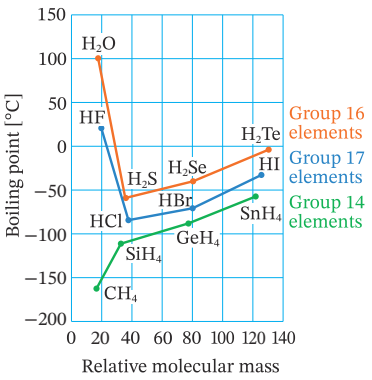
Warm Up

Answer the following questions:

(a) 90 g of water at 30 °C is heated until it turns completely into steam at 110 °C. How many kJ of heat are absorbed? Answer to two significant figures. Assume the heat needed to raise 1 g of water by 1 K is 4.2 J/(g·K), the heat needed to raise 1 g of steam by 1 K is 2.1 J/(g·K), and the heat of vaporization is 41 kJ/mol. (H = 1.0, O = 16)

_____

(b) The figure below shows the boiling points of hydrides of Group 14, 16, and 17 elements. Referring to this figure, determine whether the underlined part of the following statement is True (T) or False (F). If it is False, correct the statement.



(i) Among hydrides of the same group in Periods 3 to 5, the <u>smaller</u> the relative molecular mass, the higher the boiling point.

(ii) Because the hydrides of Group 14 elements are <u>polar</u> molecules, the boiling points of the Group 14 hydrides are low within the same period.

(iii) Because hydrogen bonds form between HF molecules, the boiling point of HF is <u>higher</u> than that of HCl.

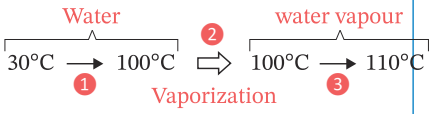
(c) Which substance has the higher boiling point, CO_2 or SiO_2? Answer with its chemical formula.

Be a Global Citizen

Access to clean water remains one of the greatest challenges facing humanity. Many countries — including Egypt, Saudi Arabia, Singapore, and Australia — use technologies based on evaporation and condensation to produce clean drinking water.

Explanation

(a) Noting that changes of state are occurring, calculate respectively:



❶ The amount of heat in the temperature change of water,

❷ The amount of heat in the change of state from water to steam,

❸ The amount of heat in the temperature change of steam.

When expressing temperature differences, absolute temperature [K] and Celsius temperature [°C] yield the same numerical value.

❶ First, the amount of heat required to heat 90 g of water at 30 °C to 100 °C: 4.2 J/(g·K) × 90 g × (100 − 30) K = 26460 J = 26.46 kJ.

❷ Next, calculate the amount of heat required to turn the water into steam. Since the molar mass of water is 18 g/mol, 90 g of water is $\frac{90\,g}{18\,g/mol} = 5.0$ mol.

The heat involved in a change of state is considered in terms of the amount of substance [mol].

Therefore, the amount of heat required to turn 5.0 mol of water at 100°C into steam at 100°C is: 41 kJ/mol×5.0 mol = 205 kJ.

❸ Finally, the amount of heat required to heat 90 g of steam at 100°C to steam at 110°C is: 2.1 J/(g·K)×90 g×(110−100) K = 1890 J = 1.89 kJ.

Therefore, the total amount of heat absorbed is: 26.46 kJ+205 kJ+1.89 kJ = 233.35 kJ ≈ 2.3×10^2 kJ.

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(b) (i) From the figure, it can be seen that for compounds of the same group in Periods 3 to 5, the larger the relative molecular mass, the higher the boiling point. → F: larger

(ii) The hydrides of Group 14 elements are non-polar molecules. Non-polar molecules have weaker Van der Waals

forces acting between them compared to polar molecules, so their boiling points are lower. → F: non-polar molecules.

(iii) **T**.

(c) CO_2 is a molecular crystal, and SiO_2 is a covalent network crystal (giant covalent structure). In covalent network crystals, ionic crystals, and metallic crystals, the forces acting between particles are stronger than intermolecular forces, so their melting points and boiling points are high. Therefore, SiO_2.

In molecules with similar structures, the greater the relative molecular mass the stronger the Van der Waals forces

Try

Choose the Correct Answer:

1. Two substances have similar relative molecular masses. Substance A boils at 100 °C, while Substance B boils at 35 °C. Which conclusion is most reasonable?

A. Substance A contains fewer molecules.

B. Substance A has stronger intermolecular forces.

C. Substance A has weaker covalent bonds.

D. Substance A contains larger atoms.

Answer: _____

2. A puddle disappears several hours after rainfall. Which explanation best accounts for this observation?

A. The water molecules were destroyed.

B. The water changed into hydrogen and oxygen gases.

C. Water molecules gained energy to enter the gaseous state.

D. The water reacted with oxygen in the atmosphere.

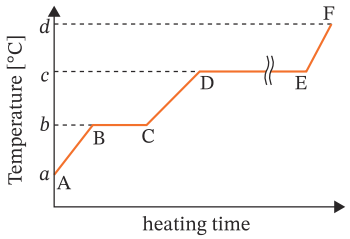
Answer: _____

Solve the Following Questions :

3. How many kJ of heat are absorbed to turn 36 g of water at 50 °C into steam at 110 °C? Answer to two significant figures. Assume the heat to raise 1 g of liquid water by 1 °C is 4.2 J/(g·°C), the heat to raise 1 g of steam by 1 °C is 2.1 J/(g·°C), and the heat of vaporization of water at 100 °C is 41 kJ/mol. (H = 1.0, O = 16)

_____

4. A solid of substance X at temperature a (°C) is heated uniformly. The figure shows the temperature change until it becomes a gas at temperature d (°C). Answer the following.



(a) What is the phenomenon during the constant-temperature interval BC called? Also state the state of substance X at that time.

_____

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(b) What are the temperatures b (°C) and c (°C) called, respectively?

_____

(c) Heat is added during intervals BC and DE, yet the temperature does not rise. What is the heat being used for?

_____

(d) What are the amounts of heat added during intervals BC and DE called, respectively?

_____

Exercise

Choose the Correct Answer::

1. Which substance is expected to have the highest boiling point?

A. CH_4 B. H_2S

C. H_2O D. CO_2

Answer: _____

2. A scientist observes that Substance X melts at a much higher temperature than Substance Y. What can be inferred?

A. Substance X has stronger attractive forces.

B. Substance X contains fewer particles.

C. Substance X has a lower molecular mass.

D. Substance X contains more gas particles.

Answer: _____

Answer on the Following Questions:

3. How many kJ of heat are required to heat 9.0 g of ice at 0 °C to water at 80 °C? Answer to two significant figures. Assume the heat of fusion of ice is 6.0 kJ/mol and the specific heat capacity of water is 4.2 J/(g·K). (H = 1.0, O = 16)

_____

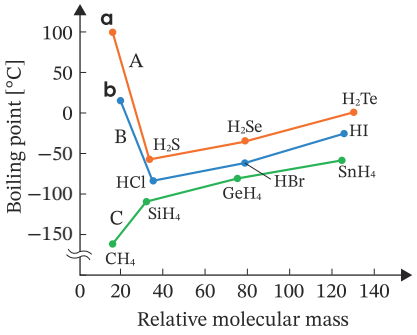
4. The figure shows the relationship between relative molecular mass and boiling point, and the groups A to C are hydrides of elements in the same group. Answer the following questions:

(a) Write the chemical formulas of the molecules corresponding to a and b.

_____

(b) In molecules with very similar structures and bonding like those in group C, generally, the larger the relative molecular mass, the higher the melting point and boiling point. State the reason for this.

_____



(c) Comparing the three compounds with the smallest relative molecular masses in groups A, B, and C, the boiling points of a and b are considerably higher compared to CH_4 in C. State the reason why such a difference occurs..

_____

Reflect and Grow

Complete:

✓ One idea that changed my thinking

.....

✓ One real-life application I discovered

.....

✓ One question I still want to investigate

.....

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Challenge Your Thinking

Water has a much lower molecular mass than H_2Te, yet water has a much higher boiling point.

_____

Can molecular mass alone explain boiling point?

_____

Develop a scientific explanation for your answer

_____

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1-2 — Vapour-Liquid Equilibrium and Vapour Pressure

✨ Engaging Introduction

When we make tea, or boil water, bubbles suddenly appear and rise to the surface. Have you ever wondered what is inside these bubbles? Are they filled with air, water vapour, or something else? And why do they form only when the water reaches a certain temperature?

In this lesson, you will investigate the relationship between vapour pressure, boiling, and vapour–liquid equilibrium to uncover the science behind this everyday phenomenon.

❓ **Guiding question:** How do particle motion and intermolecular forces determine whether a liquid evaporates, condenses, or boils?

Point!

1. Units of pressure

(a) 1 Pascal (Pa): The pressure when a force of 1 Newton (N) acts on an area of 1 m^2.
(b) 1 Hectopascal (hPa) = 100 Pa
(c) 1 Atmosphere (atm) = 1.013×10^5 Pa = 1013 hPa.

2. Vapour-Liquid Equilibrium and Vapour Pressure

A. Vapour-Liquid Equilibrium

When a liquid is placed in a closed container and left alone, two processes occur simultaneously: Evaporation, where molecules escape from the liquid surface, and Condensation, where vapour molecules return to the liquid surface.

· Kinetic energy of liquid molecules

The molecules composing a liquid do not all have the same kinetic energy.

Relationship between temperature and energy: As the temperature increases, the proportion of «high-energy molecules» able to overcome intermolecular forces and evaporate increases. Consequently the rate of evaporation (the number of molecules evaporating per unit time) increases.

· Vapour-liquid equilibrium as dynamic equilibrium

Inside a closed container the number of gaseous molecules increases over time, so the rate of condensation gradually rises. Eventually a state is reached where the **rate of evaporation equals the rate of condensation**.

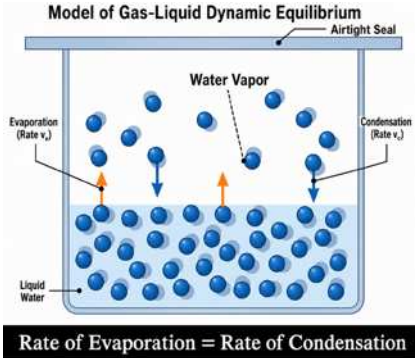

Fig 1.2.1 the relation between rate of evaporation and rate of condensation

structure of science

Key fact :

A liquid in a closed container reaches a state where evaporation and condensation occur at equal rates, called vapour–liquid equilibrium.

Key concepts:

- Vapour pressure
- Saturated vapour pressure
- Evaporation Condensation
- liquid–vapour equilibrium
- Boiling
- Atmospheric pressure
- Gas pressure
- Vacuum.

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Although it appears as if both evaporation and condensation have stopped, molecular motion has not actually ceased. This state is called Vapour-Liquid Equilibrium.

B. Vapour Pressure

The pressure exerted by the gas at vapour-liquid equilibrium is called the Saturated Vapour Pressure, or simply the Vapour Pressure.

Characteristics of vapour pressure

- **Temperature dependence:**

  As the temperature increases, the number of molecules with high kinetic energy increases, and thus the vapour pressure increases. A graph illustrating this relationship is called the Vapour Pressure Curve.

- **Substance dependence:**

  substances with weaker intermolecular forces evaporate more easily and so have a higher vapour pressure at the same temperature (e.g., Diethyl ether > Ethanol > Water).

- **Independence from volume:** The vapour pressure remains constant as long as the temperature is kept constant and liquid is present, regardless of changes in the amount of liquid or the volume of the gas in the container.

C. Boiling

A phenomenon where gas is actively generated not only from the surface of the liquid but also from its interior.

Boiling occurs when the vapour pressure equals the external pressure (atmospheric pressure).

> **Example —** from the graph, at an atmospheric pressure of 1.013×10^5 Pa water boils at 100 °C.

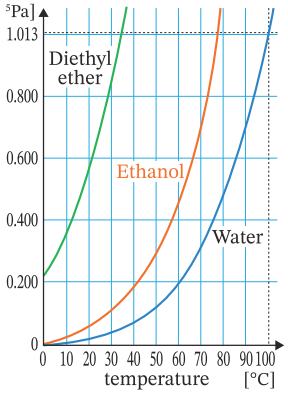


Fig 1.2.2 the relation between vapour pressure and temperature

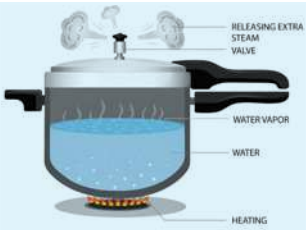
Think Critically — Claim · Evidence · Reasoning (CER)

Build your argument.

Claim: a liquid with a higher vapour pressure evaporates more readily.
Evidence: use information from the vapour-pressure graph.
Reasoning: explain how particle motion and intermolecular forces support this claim.

_____

Life Application Pressure cookers: water boils when its vapour pressure equals the surrounding atmospheric pressure. By using a sealed lid, a pressure cooker traps steam, raising the pressure and therefore the boiling point of water — so food cooks significantly faster at higher temperatures.



3. Mercury column and gas pressure

(a) **Mercury column:** Mercury column: When a glass tube closed at one end is filled with mercury and inverted into a container containing mercury, the mercury column stabilises at a certain height as shown in the right figure 1.2.3, and a mercury column is formed in the tube. At this time, the upper part becomes a vacuum.

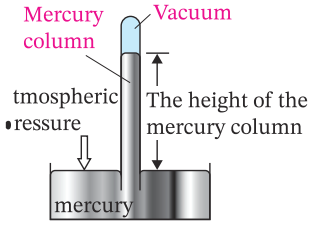


Fig 1.2.3 measuring atmospheric presure

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(b) **Mercury column and pressure**

- The height of the mercury column is directly proportional to the atmospheric pressure.
- The height of the mercury column is 760 mm at 1.013×10^5 Pa (1 atm).

⇒ Using the millimetre of mercury (symbol: mmHg),

760 mmHg = 1.013×10^5 Pa.

- If gas is introduced into the upper part of the column, the height decreases; the amount of decrease is directly proportional to the pressure of the gas.

Pressure units at a glance

Unit	Equivalent
1 atm	1.013×10^5 Pa = 1013 hPa = 760 mmHg
1 hPa	100 Pa
Boiling condition	vapour pressure = external (atmospheric) pressure

Experimental Investigation

Build Your Own Atmospheric Pressure Indicator

Materials

- Empty glass
- jar or plastic container
- balloon (or biodegradable rubber sheet)
- rubber band
- drinking straw (paper preferred
- cardboard or recycled paper
- glue or tape
- marker.

Safety precautions

Use scissors carefully when cutting

- ensure the glass jar is free from cracks
- keep the device away from excessive heat
- work under teacher supervision when using sharp tools.

Procedure

1. Cut the balloon and stretch it tightly over the opening of the jar.
2. Use a rubber band to hold it firmly in place.
3. Tape one end of the straw to the centre of the stretched balloon surface.
4. Place a piece of cardboard behind the straw and draw a simple scale with reference marks.
5. Keep the device in the same location and record the straw›s position over several days.

How it works

Changes in atmospheric pressure push on the flexible balloon membrane.

• Higher atmospheric pressure pushes the membrane downward.

• Lower atmospheric pressure allows the membrane to move upward.

As the membrane moves, the straw acts as a pointer, indicating changes in atmospheric pressure.

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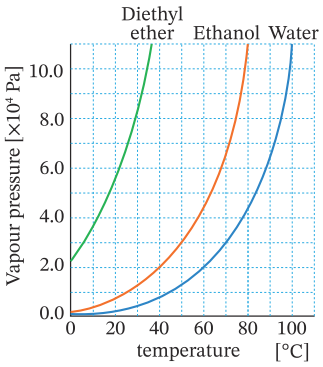
Warm Up

Answer the following questions.

(a) The graph represents the vapour-pressure curves of diethyl ether, ethanol, and water. Answer the following questions regarding these:



(i) What is the boiling point of ethanol when the atmospheric pressure is 1.0×10^5 Pa?

(ii) Among the three substances, name the one with the weakest intermolecular forces.

(iii) Among the three substances, which is least likely to evaporate at 20 °C? Name the substance.

(b) Under 25°C and 1.013×10^5 Pa, when a glass tube of 1 m length closed at one end is filled with mercury and set as shown in Figure 1, the height h of the mercury in the glass tube becomes 760 mm, and the upper part of the mercury column becomes a vacuum. The atmospheric pressure at this time is expressed as 760 mmHg. Answer the following questions:

Figure 1

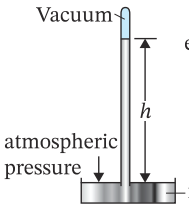
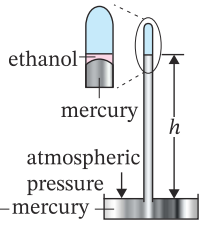


Figure 2



(i) When the atmospheric pressure is 3.039×10^4 Pa, what will h be in mm?

(ii) As shown in Figure 2, when a small amount of ethanol is introduced into the vacuum part of the glass tube and it reaches a state of vapour-liquid equilibrium, what will h be in mm at an atmospheric pressure of 1.013×10^5 Pa? Assume the saturated vapour pressure of ethanol at 25°C is 65 mmHg, and the mass of ethanol can be ignored.

Explanation

(a) (i) Since the temperature at which the atmospheric pressure and the vapour pressure become equal is the boiling point, just read the temperature when the vapour pressure is 1.0×10^5 Pa. From the graph, the temperature of ethanol when the vapour pressure is 1.0×10^5 Pa = 10.0×10^4 Pa is 78°C.

(ii) The weaker the intermolecular forces, the lower the boiling point. The substance with the lowest boiling point under 10.0×10^4 Pa is diethyl ether. Therefore, diethyl ether.

(iii) The greater the vapour pressure, the more molecules in the liquid escape to the outside, and evaporation occurs.

Therefore, the least likely to evaporate is water, which has the lowest vapour pressure at 20°C according to the graph.

(b) (i) The height of the mercury column is directly proportional to the atmospheric pressure. When the atmospheric pressure is 1.013×10^5 Pa, h is 760 mm, so h when the atmospheric pressure is 3.039×10^4 Pa is:

1.013×10^5 Pa : 760 mm = 3.039×10^4 Pa : h [mm].

h = 228 mm: Answer 228 mm

(ii) When ethanol is introduced into the upper part and it reaches a state of vapour-liquid equilibrium, inside the

Chemistry Around the World

The way people cook can be shaped by their environment. In high-altitude regions, lower atmospheric pressure causes water to boil below 100 °C. To overcome this, many households use pressure cookers, which raise the pressure inside the container and let food cook more efficiently.

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tube, the saturated vapour pressure of ethanol pushes the mercury down by 65 mmHg. Since h = 760 mm when

the upper part is a vacuum at an atmospheric pressure of 1.013×10^5 Pa, h when ethanol is introduced is:

h = 760 mm−65 mm Answer : 695 mm.

Try

Solve the Following Questions:

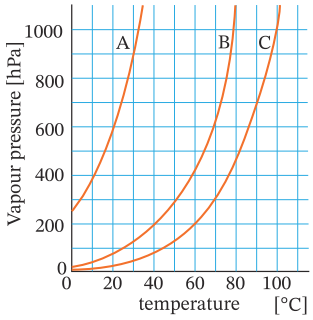
1. The figure shows the vapour-pressure curves of substances A to C. Answer the following.

(a) Which of A to C has the highest boiling point?

(b) Which of A to C has the strongest intermolecular forces?

(c) At what temperature does substance B boil when the external pressure is 800 hPa?

(d) Which of A to C is water?



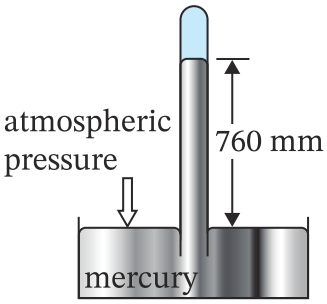
Answer: _____

2. When a glass tube of 1 m length closed at the upper end is filled with mercury and inverted into a mercury trough as shown in the figure at an atmospheric pressure of 1.0×105 Pa, the height of the mercury column in the tube was 760 mm. Answer the following questions with two significant figures.

(a) State the condition of the space in the upper part of the tube.

(b) After a cold front, the atmospheric pressure drops and the column becomes 745 mm. What is the atmospheric pressure in Pa?

(c) A small amount of gas is introduced from the bottom and the column drops to 494 mm. What is the gas pressure in the tube in Pa?



Answer: _____

Exercise

Choose the correct answer:

1. Why is atmospheric pressure lower at higher altitudes?

A. Air molecules become larger.

B. The atmosphere contains less oxygen.

C. There are fewer air molecules above the location.

D. Water vapour disappears.

Answer: _____

Answer on the Following Questions

2. The figure shows the vapour-pressure curves of substances A to C. Answer the following.

Reflect and Grow

Complete:

✓ One idea that changed my thinking

.....

✓ One real-life application I discovered

.....

✓ One question I still want to investigate

.....

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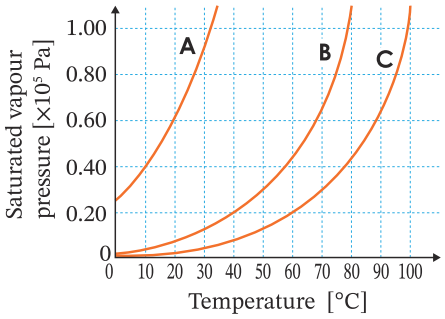
(a) From the figure, find the boiling point of A at 1.0×10^5 Pa.

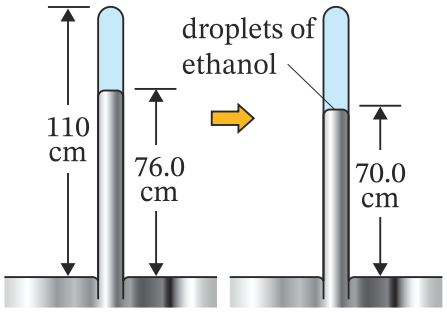
(b) What is the boiling point of water at the summit of Mount Sinai (atmospheric pressure 0.75×10^5 Pa)?

Answer: _____

(c) Write the letter of the substance with the weakest intermolecular forces.



3. Under 1.01×10^5 Pa and 25 °C, a glass tube closed at one end is filled with mercury and inverted into a trough, with 110 cm of tube above the mercury surface; the mercury column settles at 76.0 cm. When ethanol is injected it all evaporates and the column falls; with more ethanol it falls further until, when liquid ethanol droplets remain, the column becomes constant at 70.0 cm. What is the saturated vapour pressure of ethanol at 25 °C in Pa? Answer with two significant figures.



Answer: _____

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1-3 — Phase Diagram

✨ Engaging Introduction

Water can exist as ice, liquid water, or water vapour. Under certain conditions all three states can exist at the same time, and at extremely high temperatures and pressures the distinction between liquid and gas disappears completely. So how can a single substance behave in such different ways?

In this lesson, you will learn how chemists use phase diagrams to predict the state of matter and explain some of the most unusual properties of substances.

❓ **Guiding question**: How can a phase diagram help us predict and explain the physical state of a substance under different conditions?

📌 Point!

Key concept: the phase diagram of a pure substance

The state (solid, liquid, or gas) of a pure substance is determined by the conditions of temperature and pressure. A phase diagram is a graphical representation that shows the state a substance exists in at a given temperature and pressure.

📈 The phase diagram literacy

Study the phase diagram and answer:

• Which curve separates liquid and gas?

Answer: _____

• Which curve separates solid and liquid?

Answer: _____

• Which curve separates solid and gas?

Answer: _____

Support your answers using evidence from the diagram.

Answer: _____

<Phase diagram of water>

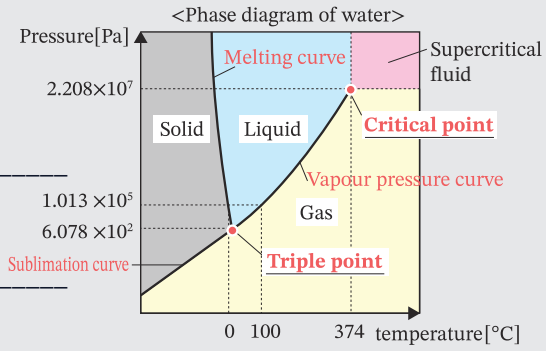

Fig 1.3.1 Phase diagram of Water

1. The three regions and three curves of a phase diagram

A phase diagram is divided into three regions by three curves, with each region corresponding to one of the three states: solid, liquid, or gas. Along the curves that separate these states, the two adjacent states coexist in equilibrium at that specific temperature and pressure.

- Melting Curve(or Fusion Curve): This is the boundary between the solid and liquid states.
- Vapour Pressure Curve: This is the boundary between the liquid and gaseous/vapour states.
- Sublimation Curve : This is the boundary between the solid and gaseous/vapour states.

⭐ Structure of Science

Key Fact :

A phase diagram shows the physical state (solid, liquid, or gas) of a pure substance at different temperatures and pressures.

Key Concepts:

the phase diagram of a pure substance

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Predict the State

A substance is located at a point inside the liquid region. Predict what will happen if:

• Temperature increases while pressure remains constant.

_____

• Pressure decreases while temperature remains constant.

_____

Use the phase diagram to justify your answer

_____

2. The triple point and the critical point

Important "points" exist on the phase diagram that demonstrate the unique properties of a substance.

- Triple Point: This is the point where the three curves intersect. At this specific temperature and pressure, the three states-solid, liquid, and gas-coexist simultaneously.

- Critical Point and Supercritical Fluid: The critical point is the specific temperature and pressure at the upper end of the vapour pressure curve, beyond which the liquid and gas phases become indistinguishable.

At temperatures and pressures higher than this point (supercritical conditions), the substance exists in a state ,where the distinction between liquid and gas ceases, exhibiting properties intermediate between the two. A substance in this state is called supercritical fluid.

Reading a phase diagram

Feature	What it marks
Melting curve	Solid ↔ liquid boundary
Vapour-pressure curve	Liquid ↔ gas boundary
Sublimation curve	Solid ↔ gas boundary
Triple point	Solid, liquid, and gas coexist
Critical point	Liquid and gas become indistinguishable

Life Application

Supercritical Fluids in Daily Life and Industry Supercritical fluids have a remarkable property: they can penetrate spaces like a gas while dissolving substances like a liquid. For instance, supercritical carbon dioxide (CO_2) is used to extract only caffeine from coffee beans (decaffeination). This technology is also used worldwide to extract perfume ingredients from Egyptian-grown jasmine and roses without damaging their delicate, heat-sensitive aromas.

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Warm Up

The figure schematically shows the phase diagram of carbon dioxide. Answer the following questions.

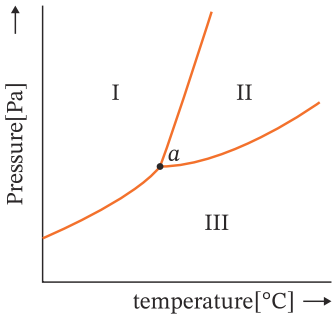
(a) In regions I, II, and III, in what state is carbon dioxide respectively? Choose the correct combination from **A** to **D**.

A. I: Gas II: Liquid III: Solid

B. I: Solid II: Gas III: Liquid

C. I: Solid II: Liquid III: Gas

D. I: Liquid II: Gas III: Solid



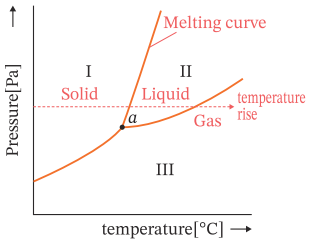
(b) Write the name of the change of state from region II to region I.

(c) How does the melting point of solid carbon dioxide change as the pressure increases?

(d) What is a point a called?

Explanation

(a) Consider that as the temperature increases at a constant pressure, the state changes from solid to liquid to gas.
Answer: C



(b) It is a change of state from liquid to solid.
Freezing (Solidification).

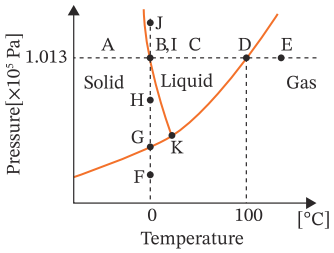
(c) The temperature at which a solid becomes a liquid is the melting point. From the melting curve in the figure, it can be seen that as the pressure increases, the melting point becomes higher.

(d) triple point .

Try

Solve the Following Questions:

1. Fill in the blanks (I) to (VIII) with the appropriate scientific terms, the phase diagram of water provided.



a) When heated from A to E, the solid begins to turn into a liquid by (I) at 0 °C.

The (II) remains constant until all the solid becomes liquid, but after all the

solid has undergone (I), the temperature rises again and the liquid state

continues up to D. The temperature at D is called (III), and that temperature is

100°C. If heating continues, (II) remains constant until all the liquid has (IV)

to from (V).

b) As pressure is increased from F to J, at G, the gas begins to form a solid by (VI),

at H, it all becomes solid, and at I, the solid (VII) to form a liquid. In this case, the density of the liquid at point J is greater than that of the solid at point H. Furthermore, the point K where the curves intersect is called (VIII).

Grand Challenge

Designing a Martian Habitat Future astronauts will need reliable sources of water. Using your understanding of phase diagrams, design a system that keeps water in the liquid state on Mars. Consider: temperature · pressure · engineering solutions. Present your design and a scientific justification.

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Exercise

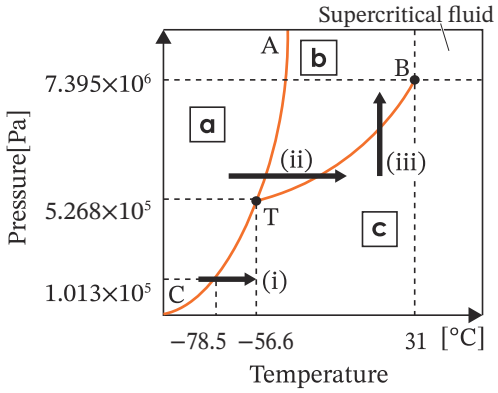
1. The figure is the phase diagram of carbon dioxide. Based on it, answer the following Questions.

(a) In what state are regions a to c, respectively?

Answer: _____

(b) What are the curves AT, BT, and CT called, respectively?

Answer: _____



(c) What is point T, where the three curves intersect, called?

Answer: _____

(d) What is the change of state indicated by arrow (i) called?

Answer: _____

(e) Briefly explain the change of state that occurs when the temperature is raised as in arrow (ii).

Answer: _____

(f) What is the change of state that occurs when the pressure is raised as in arrow (iii) called?

Answer: _____

(g) At temperatures and pressures higher than point B, the states become indistinguishable. What is point B called?

Answer: _____

Challenge Your Thinking

Draw the Journey A substance starts in the solid region.

Draw a pathway on the phase diagram that would cause it to:

1. Melt 2. Boil 3. Condense 4. Freeze

Explain each change on your diagram

_____

Reflect and Grow

Complete:

✓ One idea that changed my thinking

.....

✓ One real-life application I discovered

.....

✓ One question I still want to investigate

.....

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1-4 — Gas Laws

✨ Engaging Introduction

On a hot summer day, a bicycle tyre may feel firmer than it did on a cool morning, even though no air has been added or removed. How could a change in temperature affect the behaviour of the gas inside the tyre?

In this lesson, you will explore how pressure, volume, and temperature are related, and how chemists use mathematical models to predict the behaviour of gases in everyday life and in technology.

❓ Guiding question: How can mathematical relationships help us explain and predict the behaviour of gases under changing conditions?

Exploration

Consider:

- A bicycle tire left in the sun.
- A weather balloon rising through the atmosphere.
- A sealed gas container placed in a freezer.

Without using equations:

- What variables might be changing?

_____

- What effects do you predict?

_____

Point!

Gas Laws

(a) Boyle's law:

at constant temperature, the volume V of a given amount of gas is inversely proportional to its pressure P.

At a constant temperature, when a gas with pressure P_1 and volume V_1 changes to pressure P_2 and volume V_2, the following equation applies ● $P_1V_1 = P_2V_2$. ● PV = constant.

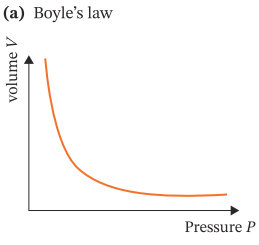

Fig 1.4.1 Boyle`s Law

(b) Charles's law:

At a constant pressure, the volume V of a given amount of gas is directly proportional to its absolute temperature T.

- At a constant pressure, when a gas with absolute temperature T_1 and volume V_1 changes to absolute temperature T_2 and volume V_2, the following equation applies: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ _____ $\frac{V}{T}$

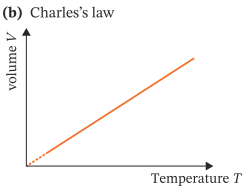

Figure 1.4.2 Charles`s law

(c) Combined gas law (Boyle–Charles's law):

The volume V of a given amount of gas is inversely proportional to its pressure P and directly

Structure of Science

Key principles

At constant temperature, the volume of a gas is inversely proportional to its pressure (Boyle's law). - At constant pressure, the volume of a gas is directly proportional to its absolute temperature (Charles's law).

Misconception Alert

Wrong

«If pressure increases, gas particles become smaller.»

Right

Gas particles do not shrink. Instead, the space between particles decreases.

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proportional to its absolute temperature T.

- When a given amount of gas with volume V1, pressure P1, and absolute temperature T1 changes to volume V2 , pressure P2, and absolute temperature T2, the following equation applies: $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$.

(d) **Application of the gas laws**

- To find the volume, pressure, or temperature of a given amount of gas, **the combined gas law** is used

- When using the gas laws, the temperature must be expressed as **absolute temperature [K]**.

Equation box

Law	Condition	Relation
Boyle's law	constant T	$P_1V_1 = P_2V_2$ (PV = constant)
Charles's law	constant P	$V_1 / T_1 = V_2 / T_2$ (V / T = constant)
Combined gas law	—	$P_1V_1 / T_1 = P_2V_2 / T_2$ (PV / T = constant)

🥇 Appreciating Scientists

In the seventeenth century, Robert Boyle carefully investigated the relationship between pressure and volume. His experiments demonstrated that scientific laws can emerge from systematic observations, precise measurements, and mathematical analysis.

🔬 Think Like a Chemist

Chemists rarely measure every property of a gas directly. Instead, they use established relationships to predict unknown quantities from known measurements.

When solving a gas-law problem, ask yourself:

- Which variables are changing?

_____

- Which variables remain constant?

_____

- Which gas law best describes the situation?

_____

Scientific Application: Designing Safe Gas Container

Engineers must consider changes in pressure and temperature when designing gas cylinders used in hospitals, laboratories, and industries.

- An unsafe design could lead to dangerous pressure build-up.
- Gas laws help in predicting these changes and design safer technologies.

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Warm Up

Answer the following questions.

(a) A sample of gas has a volume of 200 mL at a pressure of 4.0×10^4 Pa. If the volume is changed to 1.0 L at constant temperature, what is the new pressure in Pa? (Two significant figures.)

(b) A sample of gas occupies 60 L at 27 °C and 1.0×10^5 Pa. If the temperature is changed to 87 °C and the pressure to 2.5×10^5 Pa, what will the new volume be in L? (Two significant figures.)

NOS: Why Do Scientific Models Matter?

Gas laws do not describe individual gas particles. Instead, they provide models that help scientists explain and predict the collective behavior of millions of particles.

Explanation

(a) Since we need to find the pressure of a given amount of gas, we use combined gas law:

$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$.

Let the required pressure be P [Pa].

The pressure before the change is P1 = 4.0×10^4 Pa, and the volume is V_1 = 200 mL = 0.200 L.

The pressure after the change is P_2 = P [Pa], and V_2 = 1.0 L. Therefore,

$$\frac{4.0 \times 10^4 \text{Pa} \times 0.200 \text{L}}{T_1} = \frac{P[\text{Pa}] \times 1.0 \text{L}}{T_2}$$

Also, since the temperature is constant, $T_1 = T_2$, so 4.0×10^4 Pa×0.200 L = P [Pa]×1.0 L.

$$P = \frac{4.0 \times 10^4 \text{Pa} \times 0.200 \text{L}}{1.0 \text{L}}$$

= 8.0×10^3 Pa

(b) Since we need to find the volume of a given amount of gas, we use combined gas law: $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$

Let the required volume be V [L].

The temperature before the change is T_1 = (27+273) K, the pressure is P_1 = 1.0×105 Pa, and the volume is V_1 = 60 L.

The temperature after the change is T_2 = (87+273) K, the pressure is P_2 = 2.5×105 Pa, and the volume is V_2 = V [L]. Therefore,

$$\frac{1.0 \times 10^5 \text{Pa} \times 60 \text{L}}{(27 + 273)\text{K}} = \frac{2.5 \times 10^5 \text{Pa} \times V[\text{L}]}{(87 + 273)\text{K}}$$

$$\frac{1.0 \times 10^5 \text{Pa} \times 60 \text{L}}{300 \text{K}} = \frac{2.5 \times 10^5 \text{Pa} \times V[\text{L}]}{360 \text{K}}$$

$$V = \frac{1.0 \times 10^5 \text{Pa} \times 60 \text{L} \times 360 \text{K}}{300 \text{K} \times 2.5 \times 10^5 \text{Pa}}$$

$$= \frac{72}{2.5}$$

= 28.8

≈ 29 L

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Try

Answer the following questions:

(a) When 4.0 L of a gas at 1.0×10^5 Pa is subjected to a pressure of 2.0×10^5 Pa at constant temperature, what will the volume be in L? (Two significant figures.)

Answer: _____

(b) To expand 2.00 L of a gas at 27 °C and 2.0×10^5 Pa to 2.50 L at constant pressure, what should the temperature be in °C? (Nearest whole number.)

Answer: _____

(c) When a gas at 0 °C and 1.0×10^5 Pa is raised to 97 °C at constant volume, what will the pressure be in Pa? (Two significant figures.)

Answer: _____

(d) When 500 mL of a gas at 77 °C and 3.0×10^5 Pa is changed to 47 °C and 2.0 L, what will the pressure be in Pa? (Two significant figures.)

Answer: _____

Exercise

Choose the correct answer:

1. A balloon is cooled while the pressure remains constant. According to Charles's law:

A. Volume increases.

B. Volume decreases.

C. Pressure increases.

D. Number of moles increases.

Answer: _____

2. A student calculates a gas volume using the combined gas law and obtains a value larger than the initial volume. Which situation could explain this result?

A. Pressure increased while temperature stayed constant.

B. Temperature increased while pressure decreased.

C. Temperature decreased while pressure increased.

D. Both temperature and volume decreased.

Answer: _____

3. Answer the following questions:

(a) When 5.0 L of a gas at 1.0×10^5 Pa is compressed to 1.0 L at constant temperature, what will the pressure be in Pa? (Two significant figures.)

(b) When 320 mL of a gas at 10 °C and 5.0×10^5 Pa is subjected to 4.0×10^5 Pa at constant temperature, what will the volume be in mL? (Two significant figures.)

(c) When 3.0 L of a gas at 7 °C and 1.0×10^5 Pa is raised to 127 °C at constant pressure,

Reflect and Grow

Complete:

✓ One idea that changed my thinking

.....

✓ One real-life application I discovered

.....

✓ One question I still want to investigate

.....

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what will the volume be in L? (Two significant figures.)

(d) To expand 2.00 L of a gas at 7 °C to 6.00 L at constant pressure, what should the temperature be in °C? (Nearest whole number.)

(e) When 3.0 L of a gas at 7 °C and 1.5×10^5 Pa is raised to 127 °C at constant volume, what will the pressure be in Pa? (Two significant figures.)

(f) To raise the pressure of a gas at 27 °C and 2.00×10^5 Pa to 2.20×10^5 Pa at constant volume, what should the temperature be in °C? (Nearest whole number.)

(g) When 2.0 L of a gas at 23 °C and 1.5×10^5 Pa is changed to 117 °C and 3.0 L, what will the pressure be in Pa? (Two significant figures.)

(h) When 600 mL of a gas at 17 °C and 2.0×10^5 Pa is changed to 0 °C and 9.1×10^4 Pa, what will the volume be in L? (Two significant figures.)

Answer: _____

Challenge Your Thinking

A weather balloon is launched from sea level and rises to an altitude where the atmospheric pressure is much lower than at the surface. Without performing calculations:

- Predict how the balloon's volume will change.

_____

- Explain your reasoning using particle theory.

_____

- Identify which gas law best supports your prediction.

_____

-Sketch a simple diagram to communicate your thinking.

_____

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1-5 — Ideal Gas Equation

✨ Engaging Introduction

A chemist discovers a sealed container filled with an unknown gas. By measuring only its pressure, volume, temperature, and mass, the chemist can identify important characteristics of the gas without ever observing its particles directly. Let's explore how chemists use measurements and mathematical models to uncover the secrets of gases.

❓ **Guiding question**: How can one equation help scientists explain and predict the behaviour of gases under different conditions?

Exploration

Consider the following situations:

- Bread dough rising in an oven.
- A sealed juice box expands when left in a hot car.
- A camping gas canister used in cold weather.
- A scuba diver breathing compressed air underwater.

Without using calculations:

- Which variables might change?
- Which variables might remain constant?
- What observations would you expect?

Point!

The Ideal Gas Law

The relationship between the state variables of a gas-pressure (P), volume (V), absolute temperature (T), and the amount of substance (n)-is consolidated into a single mathematical expression known as the **Ideal Gas Law** . This can be logically derived from the Combined Gas Law (Boyle-Charles' Law).

Step 1 — Starting with one mole of gas

First, recall the Combined Gas Law (Boyle-Charles' Law). For a fixed amount of gas, this law states that the product of its pressure and volume is directly proportional to its absolute temperature.

If we consider 1 mole of gas, we define the molar volume as v [L/mol] and the constant as R. This leads to the following equation:

Pv = RT

Step 2 — Determining the molar gas constant (R)

Irrespective of the gas species, 1 mole of any ideal gas occupies a molar volume of 22.4 L/mol at standard conditions (0 °C = 273 K, $1.01^3 \times 10^5$ Pa).

By substituting these standard values into the previous equation (Pv = RT), we can calculate the constant R, which is termed the Molar Gas Constant.

$$R = \frac{PV}{T} = \frac{1.013 \times 10^5 \text{Pa} \times 22.4 \text{L/mol}}{273 \text{K}} = 8.31 \times 10^3 \frac{\text{Pa} \cdot \text{L}}{\text{mol} \cdot \text{K}}$$

Structure of Science

Key Fact :

The Ideal Gas Law combines the patterns discovered by earlier scientists into a single equation that explains and predicts gas behaviour over a wide range of conditions.

Key Concepts:

· Pressure

· Volume

· Molar volume

· Molar mass

· Molar gas constant (R).

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Step 3 — Extending to n moles (completing the Ideal Gas Law)

When the amount of substance is n [mol], the total volume V is n times the molar volume v (V = nv), so v = V ÷ n. Substituting into Step 1, then multiplying both sides by n and rearranging gives the complete equation of state: $PV = nRT$.

Application of the Ideal Gas Law: determination of molar mass

The Ideal Gas Law is also a key tool for finding the molar mass of an unknown gas. If ω [g] is the mass of the gas and M [g/mol] its molar mass (numerically equal to the relative molecular mass), then $n = \frac{\omega}{M}$. Substituting into the Ideal Gas Law gives the following relationship.

$$PV = \frac{\omega}{M}RT$$

Using this equation, you can calculate the molar mass (M) of the gas from experimentally measured values, such as its mass and volume.

📦 Equation box

Quantity	Relation
Ideal gas law (1 mol)	Pv = RT
Molar gas constant	R = 8.31 × 10^3 Pa·L/(mol·K)
Ideal gas law (n mol)	PV = nRT
Molar mass form	PV = (ω / M) RT

Life Application

Heat and Car Tyres : Heatwaves and Car Tyres Take care to prevent car-tyre blowouts in summer, when the asphalt surface is extremely hot. The Ideal Gas Law, PV = nRT, explains the danger: with the amount of air (n) and the volume (V) inside the tyre roughly constant, a rapid rise in air temperature (T) from the hot road raises the internal pressure (P) proportionally,

Mathematics in Chemistry

Application of the Ideal Gas Law:

determination of molar mass Scientific equations are not simply mathematical shortcuts. They are models built from experimental evidence.

The Ideal Gas Equation allows scientists to:

- Predict behavior.
- Test hypotheses.
- Analyze data.
- Communicate results quantitatively.

Warm Up

Answer with two significant figures. Assume R = 8.3 × 10^3 Pa·L/(K·mol).

(a) Answer the following.

(i) There is 8.3 L of gas at 27 °C and 3.0 × 10^5 Pa. What is the amount of substance in mol?

(ii) When 1.0 mol of gas is expanded to 24.07 L at 17 °C, what is the pressure in Pa?

(b) A certain gas had a density of 0.53 g/L at 27 °C and 3.0 × 10^4 Pa. What is the relative molecular mass of this gas?

Explanation

(a) (i) To determine the amount of substance, we use the ideal gas equation. Let the required amount of substance be n [mol]. From the ideal gas equation PV = nRT:

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3.0×10^5 Pa × 8.3 L = n [mol] × 8.3×10^3 Pa.L/(K.mol) × (27+273) K

- Convert the unit of temperature to [K].

$$n = \frac{3.0\times10^5 \text{ Pa} \times 8.3 \text{ L}}{8.3\times10^3 \text{ Pa·L/(K·mol)} \times (27+273) \text{ K}}$$

$$= \frac{3.0\times10^5 \text{ Pa} \times 8.3 \text{ L}}{8.3\times10^3 \text{ Pa·L/(K·mol)} \times 300 \text{ K}}$$

= 1.0 mol

(ii) Since the amount of substance is given, we use the ideal gas equation. Let the required pressure be P [Pa]. From the ideal gas equation PV = nRT:

$$P \text{ [Pa]} \times 24.07 \text{ L} = 1.0 \text{ mol} \times 8.3\times10^3 \text{ Pa·L/(K·mol)} \times (17+273) \text{ K}$$

$$P = \frac{1.0 \text{ mol} \times 8.3\times10^3 \text{ Pa·L/(K·mol)} \times (17+273) \text{ K}}{24.07 \text{ L}}$$

$$= \frac{1.0 \text{ mol} \times 8.3\times10^3 \text{ Pa·L/(K·mol)} \times 290 \text{ K}}{24.07 \text{ L}}$$

$$= \frac{24.07\times10^5}{24.07}$$

$= 1.0\times10^5$ Pa

(b) The relative molecular mass is determined from the molar mass [g/mol].

Let the molar mass of this gas be M [g/mol]. Since the density is 0.53 g/L, the mass is 0.53 g when the gas volume is 1.0 L.

Therefore, the amount of substance of this gas is $\frac{0.53}{M}$ [mol]. Amount of substance [mol] = $\frac{\text{Mass [g]}}{\text{Molar mass [g/mol]}}$

Now that the amount of substance is known, using the ideal gas equation PV = nRT:

3.0×10^4 Pa × 1.0 L = $\frac{0.53}{M}$ [mol] × 8.3×10^3 Pa.L/(K.mol) × (27+273) K

$$M = \frac{0.53 \times 8.3\times10^3 \text{ Pa·L/(K·mol)} \times (27+273) \text{ K}}{3.0\times10^4 \text{ Pa} \times 1.0 \text{ L}}$$

$$= \frac{0.53 \times 8.3\times10^3 \text{ Pa·L/(K·mol)} \times 300 \text{ K}}{3.0\times10^4 \text{ Pa} \times 1.0 \text{ L}}$$

$= 0.53 \times 8.3\times10$

$= 43.99$

≈ 44 g/mol

Therefore, the relative molecular mass of this gas is 44 g/mol

Try

Solve the following Questions:

1. Assume the gas constant R = 8.3×10^3 Pa·L/(K·mol).(O = 16)

(a) When 0.40 mol of gas is subjected to a pressure of 2.0×10^5 Pa at 57°C, what will the volume be in L?

_____

(b) 0.32 g of oxygen was placed in a 500 mL container at 27°C. What is the pressure inside this container in Pa

_____

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2. Answer to the nearest whole number. Assume $R = 8.3 \times 10^3$ Pa·L/(K·mol).

(a) When 1.2 g of a volatile substance was completely vaporized, its volume was 1.2 L at 77 °C and 1.0×10^5 Pa. Find the relative molecular mass.

(b) Find the relative molecular mass of a gas whose mass is 7.6 g for a volume of 4.15 L at 17 °C and 2.32×10^5 Pa.

(c) Find the relative molecular mass of a gas with a density of 2.4 g/L at 27 °C and 1.00×10^5 Pa.

Exercise

Choose the correct answer:

1. Why is the value of R the same for all ideal gases?

A. All gases have the same colour under the same conditions.

B. All gases have the same mass under the same conditions.

C. All gases behave the same way under the same conditions.

D. All gases have the same density under the same conditions.

2. A chemist measures the mass, pressure, volume, and temperature of an unknown gas and uses the Ideal Gas Law to calculate its molar mass. Which quantity must be measured in addition to P, V, and T?

A. Atomic radius

B. Gas colour

C. Mass of the gas sample

D. Density of water

Answer: _____

Answer on the Following Questions:

3. Assume $R = 8.3 \times 10^3$ Pa·L/(K·mol).

(a) There is 0.10 mol of carbon dioxide with a volume of 2.9 L at 17 °C. What is its pressure in Pa?

Answer: _____

(b) When 2.0 mol of gas is subjected to 1.2×10^5 Pa at 27 °C, what will the volume be in L?

Answer: _____

(c) To expand 0.50 mol of gas to 33.2 L at 4.0×10^4 Pa, what should the temperature be in °C?

Answer: _____

(d) What is the amount of substance in mol of 16.6 L of gas at 127 °C and 3.0×10^5 Pa?

Answer: _____

Challenge Your Thinking

Designing an Investigation

A gas sample occupies 2.50 L at 27°C and 1.00×10^5 Pa.

The temperature is increased until the pressure doubles while the volume remains constant.

Without performing calculations:

- Predict what happens to the average kinetic energy of the gas particles. _____
- Explain how the particle collisions change. _____
- Justify your answers using the Ideal Gas Equation _____

Reflect and Grow

Complete:

✓ One idea that changed my thinking

.....

✓ One real-life application I discovered

.....

✓ One question I still want to investigate

.....

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1-6 — Total Pressure and Partial Pressure

✨ Engaging Introduction

Imagine a deep-sea diver breathing a special gas mixture, or an astronaut inside a spacecraft surrounded by carefully controlled gases. What will they feel in each case? Let's explore Dalton's law and how it explains why the pressure of each gas in a breathing tank increases with depth — affecting a diver's safety underwater.

❓ **Guiding question:** How can invisible gases share the same space but still behave as independent gases?

Exploration

(hook phenomena)

A scuba diver uses a mixture of oxygen and nitrogen instead of pure oxygen.Why?

- Oxygen is necessary for life.
- Nitrogen affects the total pressure.
- Changing the ratio of gases changes the pressure effects on the diver's body.

Point!

Total Pressure and Partial Pressure

(a) Total pressure: the pressure of a gas mixture (several gases that do not react with each other).

(b) Partial pressure: the pressure each component gas would exert if it alone occupied the same volume as the mixture.

(c) Dalton's law of partial pressures: Under a constant volume and temperature, the total pressure of a gas mixture is equal to the sum of the partial pressures of its component gases.

- If the total pressure of a gas mixture is P and the partial pressures of its component gases are P_1, P_2, P_3, ...,

then the following equation applies: $P = P_1+P_2+P_3+...$

⚠ Misconunderstanding Alert

✖ **Wrong idea:**

"After mixing gases, each gas loses its own pressure."

✓ **Correct:**

Each gas keeps its own partial pressure and contributes to total pressure.

✖ **Wrong idea:**

"The largest gas molecule creates the highest pressure."

✓ **Correct:**

Pressure depends mainly on the number of particles, not molecule size.

Structure of Science

Key Fact :

The behaviour of a gas mixture can be predicted by analysing the contribution of each component gas through its mole fraction and partial pressure.

Key Concepts:

- Total pressure
- Partial pressure
- Mole fraction
- Gas mixtures
- Average relative
- molecular mass
- Vapour pressure
· Atmospheric pressure.

Scientific law:

Dalton's law of partial pressures.

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(d) Mole fraction: : The ratio of the amount of substance of each component gas to the total amount of substance of the gas mixture.

- If the amount of substance of gas A is nA [mol] and the amount of substance of gas B is nB [mol], the mole fraction of gas A in the mixture of gas A and gas B is $\frac{n_A}{n_A + n_B}$, and the mole fraction of gas B is $\frac{n_B}{n_A + n_B}$.
- The partial pressure of each component gas in a gas mixture can be expressed as:

Partial pressure = Total pressure × Mole fraction .

(e) **Relationship between partial pressure, volume, and amount of substance**

- At a constant temperature and volume, the ratio of the partial pressures of the component gases in a gas mixture is equal to the ratio of their amounts of substance.
- At a constant temperature and pressure, when each component gas is extracted individually, the ratio of the volumes of the component gases in the gas mixture is equal to the ratio of their amounts of substance.

(f) **Average relative molecular mass**

The apparent relative molecular mass of a mixture, assuming it consists of a single type of molecule, is the average relative molecular mass. It equals the sum of Relative molecular mass × Mole fraction of each component.

(g) **Partial pressure of a gas collected over water**

The gas collected over water is mixed with water vapour.

When the water levels inside and outside the collection container are equalized, the total pressure of the collected gas equals the atmospheric pressure.

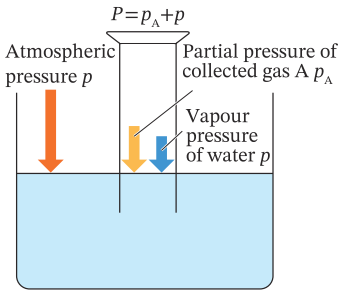

Figure 1.6.1. Measuring the atmospheric Pressure

As shown in the right figure 1.6.1, when gas A is collected over water, Atmospheric pressure = Total pressure of the collected gas = Partial pressure of gas A + Vapour pressure of water .

By rearranging this, we obtain: Partial pressure of gas A = Atmospheric pressure − Vapour pressure of water .

Equation box

Quantity	Relation
Dalton's law	$P = P_1 + P_2 + P_3 + \ldots$
Mole fraction of A	x_A = nA / (nA + nB)
Partial pressure	Partial pressure = total pressure × mole fraction
Average relative molecular mass	Σ (relative molecular mass × mole fraction)
Collected over water	Partial pressure of gas = atmospheric − water-vapour pressure

Testing Hypothesis (Scientific Inquiry)

Hypothesis:

„If the amount of gas increases inside a fixed-volume container, then its partial pressure will increase because more particles collide with the container walls.“

Variables:

- Independent variable _____
- Dependent variable: _____
- Controlled variables: _____

Evidence Collection: _____

Investigation Design: _____

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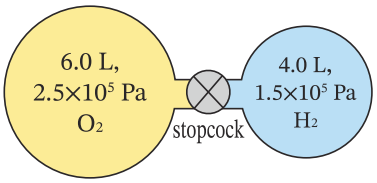
Warm Up

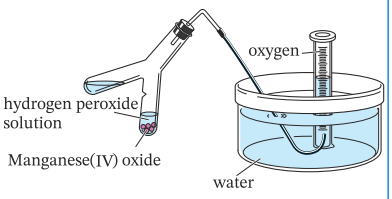
Answer the following questions.

There is a 6.0 L container with oxygen at 2.5×10^5 Pa and a 4.0 L container with hydrogen at 1.5×10^5 Pa at the same temperature.



Find the partial pressure of oxygen and the total pressure in the containers when the two containers are connected, the stopcock is opened, and kept at the same temperature for a sufficiently long time.

As shown in the figure on the right, oxygen was collected over water, and when the water levels inside and outside the measuring cylinder were equalized, its volume was 0.83 L at 1.03×10^5 Pa and 27°C. Answer the following questions with two significant figures. Assume the gas constant $R = 8.3\times10^3$ Pa.L/(K.mol).



(i) Assuming the saturated vapour pressure of water at 27°C is 3.0×10^3 Pa, what is the partial pressure of the collected oxygen in Pa?

(ii) Find the amount of substance of the collected oxygen

Explanation

(a) To calculate the partial pressure of oxygen, consider the pressure when oxygen alone occupies the same volume as the gas mixture. When the two containers are connected, the volume of the gas mixture becomes 10.0 L.

Therefore, if the partial pressure of oxygen is P_A [Pa], from Boyle's law $P_1V_1 = P_2V_2$:

2.5×10^5 Pa × 6.0 L = P_A [Pa] × 10.0 L

$P_A = 1.5\times10^5$pa

Similarly, if the partial pressure of hydrogen is PB [Pa], from Boyle's law:

1.5×10^5 Pa × 4.0 L = P_B [Pa] × 10.0 L

$P_B = 6.0\times10^4$ Pa

Since the total pressure in the container is the sum of the partial pressures:

P_A [a]+P_B[Pa] = 1 .5× 10^5 Pa + 6.0 ×10^4 pa = 2.1× 10^5 pa

Therefore, the partial pressure of oxygen is 1.5×10^5 Pa, and the total pressure is 2.1×10^5 Pa.

(b) (i) If the partial pressure of oxygen is Px [Pa], from Partial pressure of oxygen = Atmospheric pressure − Vapour pressure of water:

$P_x = 1.03\times10^5 - 3.0\times10^3 =$ Answer: 1.0×10^5 Pa

(ii) From the ideal gas equation PV=nRT:

1.0×10^5 Pa × 0.83 L = n × 8.3×10^3 Pa.L/(K.mol) × (27+273) K

$n = 3.33\times10^{-2}$

$\approx 3.3\times10^{-2}$ Answer: 3.3×10^{-2} mol

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Try

1. As shown in the figure, nitrogen (relative molecular mass 28) at 2.0×10^5 Pa is placed in a 3.0 L container A, and hydrogen (relative molecular mass 2.0) at 1.0×10^5 Pa is placed in a 2.0 L container B. The stopcock is opened to mix the two gases.

The temperature was kept constant at all times. Answer the following questions about the mixed gas with two significant figures.

(a) What is the partial pressure of nitrogen in Pa?

Answer: _____

(b) What is the total pressure in Pa?

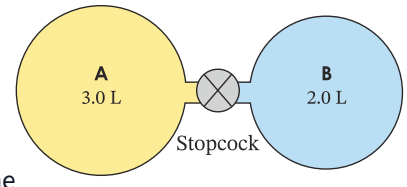
Answer: _____

(c) What is the mole fraction of each gas?

Answer: _____

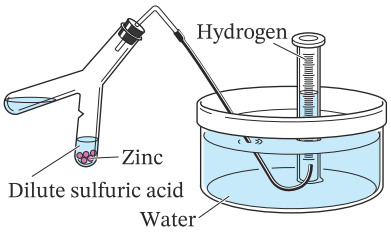
(d) What is the average relative molecular mass of the mixture?

Answer: _____



2. Hydrogen was collected over water, and when the water levels inside and outside the measuring cylinder were equalized, 498 mL of gas was obtained at 27°C and 1.04×10^5 Pa. What is the amount of substance in mol of the obtained hydrogen?

Answer with two significant figures. Assume the gas constant R = 8.3×10^3 Pa·L/(K·mol) and the vapour pressure of water at 27°C is 4.0×10^3 Pa.



Exercise

Choose the correct answer:

1. A sample of hydrogen is collected over water. The atmospheric pressure is 101 kPa and the water-vapour pressure is 3 kPa. What is the partial pressure of hydrogen?

A. 98 kPa B. 101 kPa

C. 104 kPa D. 3 kPa

Answer: _____

2. A student claims that increasing the amount of nitrogen in a mixture will increase the partial pressure of oxygen. Which statement best evaluates this claim?

A. Correct, because all partial pressures increase together.

B. Correct, because total pressure stays constant but molar mass increases.

C. Incorrect, because oxygen's partial pressure depends on its own mole fraction.

D. Incorrect, because nitrogen does not contribute to pressure.

Answer: _____

3. Answer the following questions with two significant figures.

(a) Maintaining the same temperature, gas A at 6.0×10^4 Pa, 250 mL and gas B at 4.0×10^4 Pa, 150 mL were placed in a 500 mL container. Answer the following questions.

(i) Find the partial pressure of gas A.

_____

(ii) Find the partial pressure of gas B.

Reflect and Grow

Complete:

✓ One idea that changed my thinking

.....

✓ One real-life application I discovered

.....

✓ One question I still want to investigate

.....

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_____

(iii) Find the total pressure of the gas mixture.

_____

(b) At a constant temperature, when the pressure of a gas mixture of 4.8 g of methane CH_4 and 2.8 g of carbon monoxide CO is 1.0×10^5 Pa, what is the partial pressure of methane in Pa? (H = 1.0, C = 12, O = 16)

_____

4. Oxygen was generated by adding manganese(IV) oxide to hydrogen peroxide solution, and it was collected with a measuring cylinder over water under an atmospheric pressure of 1.0×10^5 Pa at 27°C. When the water levels inside and outside the measuring cylinder were equalized, the volume of the collected gas was 700 mL. Find the amount of substance of the oxygen generated at this time with two significant figures. Assume the saturated vapour pressure of water at 27°C is 3.6×10^3 Pa and the gas constant is 8.3×10^3 Pa·L/(K·mol)

🤔 **Think Critically** — A scientist analyzes air from two different locations:

- Location A: High mountain area
- Location B: Sea level

Both samples contain oxygen and nitrogen.

1. if the percentage of oxygen is almost the same in both locations, but the total pressure is different. Why does the oxygen partial pressure change?

_____

2. If the amount of oxygen stays constant but nitrogen is added, what happens to:

- Total pressure?_____
- Oxygen partial pressure?_____

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1-7 — Ideal Gas and Real Gas

✨ Engaging Introduction

A balloon left outside on a cold morning becomes smaller, but when placed in sunlight it expands again. Let›s explore why the gas inside behaves differently when the temperature changes.

❓ **Guiding question:** Why do real gases deviate from ideal behaviour, and how can scientists explain these deviations?

Exploration

Consider the following situations:

• Gas stored in a scuba tank at extremely high pressure.

• Liquid nitrogen slowly warming to room temperature.

• Carbon dioxide compressed in a fire extinguisher.

• Natural gas transported through long pipelines.

Discuss:

• Would you expect gases to behave ideally in these situations?

_____

• Which conditions might cause deviations?

_____

• What evidence would help you test your prediction?

_____

Point!

The ideal gas equation of state, PV = nRT, does not perfectly describe all gases. Real gases deviate from ideal behaviour because of the finite size of their molecules and the intermolecular forces between them.

A. Definitions of ideal gases and real gases

- Ideal Gas: a hypothetical model assumed to simplify calculations.

(1) The volume of the gas molecules themselves is zero.

(2) No intermolecular forces act between the molecules.

- Real Gas: gases that actually exist, such as hydrogen or nitrogen.

(1) The molecules have a small, finite volume.

(2) Attractive (intermolecular) forces act between the molecules.

B. Why do deviations occur?

The deviation of a real gas from ideal behaviour is quantified by the Compression Factor (Z):

$Z = \frac{PV}{nRT}$.

structure of science

Key Fact :

An ideal gas is a simplified model in which gas particles have no volume and no intermolecular forces.

Key Concepts:

Ideal gas · Real gas · Intermolecular forces · Molecular volume · Compression factor (Z)

Scientific principles: intermolecular attractions reduce the observed pressure; finite molecular volume becomes important at high pressures.

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For an ideal gas, Z is always equal to 1. However, for a real gas, the value of Z varies depending on the conditions of **pressure** and **temperature**. This variation is related to the following two physical factors.

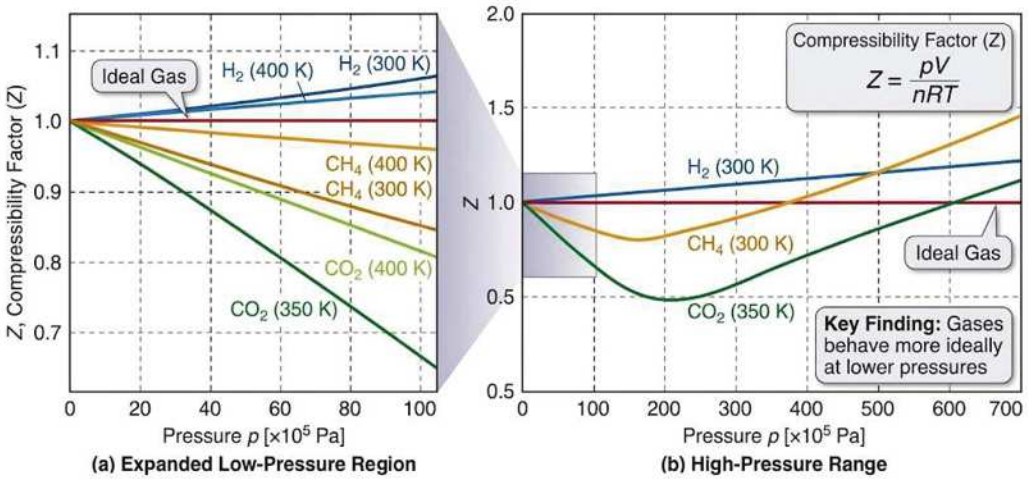
(i) When attractive forces act between molecules, the force with which the molecules collide with the container walls is weakened. As a result, the **observed pressure, P, is lower than that predicted for an ideal state**.

This effect is pronounced under conditions of **moderate pressure** (where molecules are closer together) and **low temperature**, causing Z to be less than 1.

(ii) Effect of Molecular Volume (Reason for Z>1)

At very high pressures, the **volume of the molecules themselves** is no longer negligible compared to the total volume, V, of the gas. Since the **free volume available for molecular motion effectively decreases**, the gas becomes harder to compress further.

Consequently, the observed volume, V, is greater than the calculated ideal value, and Z significantly exceeds 1 under these conditions.



1-7-1 Compressibility Factor (Z) vs. Pressure for Real Gases

C. Conditions for approaching ideal-gas behaviour

(i) **Effect of pressure:**

When a real gas is compressed, increasing the pressure, the number of molecules per unit volume increases, and thus the proportion of volume occupied by the molecules themselves becomes significant. Due to the influence of this molecular volume, the actual volume of the gas becomes greater than that of an ideal gas.

When the pressure is lowered, the number of molecules per unit volume decreases. This minimises the effect of molecular volume, causing the real gas to approach ideal behaviour.

(ii) **Effect of temperature:**

As the temperature of a real gas is lowered, the thermal motion of the molecules slows down, and the effect of intermolecular forces becomes greater. This results in the actual pressure of the gas being lower than that of an ideal gas.

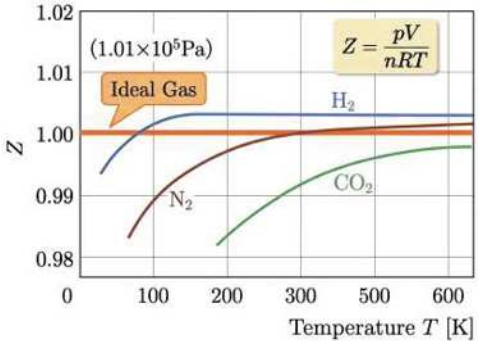


Figure 1.7.2 the effect of temperature on Ideal gas

Graph Literacy

Reading the Compression Factor Graph

Before reading the explanation:

- Where is Z equal to 1?
- Where is Z less than 1?
- Where is Z greater than 1?
- Which region suggests stronger intermolecular attractions?
- Which region suggests the effect of molecular volume?

Graph Detective

Use evidence from the graph to support your answers.

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Conversely, raising the temperature increases the kinetic energy (thermal motion) of the molecules, which minimises the effect of intermolecular forces, causing the real gas to approach ideal behaviour.

Therefore, a real gas can be treated as an ideal gas under conditions of high temperature and low pressure.

Think as an Engineer

Engineers who design:

- Industrial gas tanks
- Deep-sea diving systems
- Spacecraft fuel systems

cannot assume perfect gas behavior under all conditions. Ignoring real-gas effects could lead to inaccurate predictions and unsafe designs.

Why is understanding model limitations important in engineering?

_____

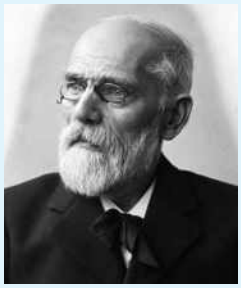
_____

D. [Advanced] A more accurate model: the Van der Waals equation of state

The **Van der Waals equation of state** *was developed to account for real-gas deviations. It adds a correction term for intermolecular forces, a, and one for molecular volume, b:*

$$(P+\frac{n^2}{V^2}a)(V-nb)=nRT$$

Appreciating Scientists

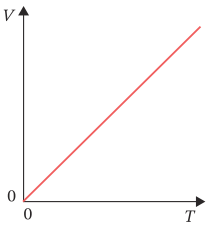


While many scientists used the Ideal Gas Model successfully, Johannes Diderik van der Waals recognized that real gases possess molecular volume and intermolecular attractions.

His work led to the development of a more realistic equation of state and transformed our understanding of matter.

E. Ideal Gas And The Ideal Gas Equation

For an ideal gas, since the ideal gas equation PV = nRT holds, the relationship between pressure, volume, amount of substance, and temperature can be determined.



Example 1 *— Relationship between volume and temperature when the pressure of a given amount of gas is constant In PV = nRT, P and n can be regarded as constants.*

Solving for V, $V=\underbrace{\frac{nR}{P}}_{\text{Constant}}T$

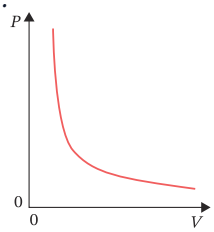
Therefore, the volume V is directly proportional to the temperature T.

Example 2 *— Relationship between volume and pressure when the temperature of a given amount of gas is constant*

In PV = nRT, n and T can be regarded as constants.

Solving for V, $V=\underbrace{\frac{nRT}{P}}_{\text{Constant}}$

Therefore, the volume V is inversely proportional to the pressure P.



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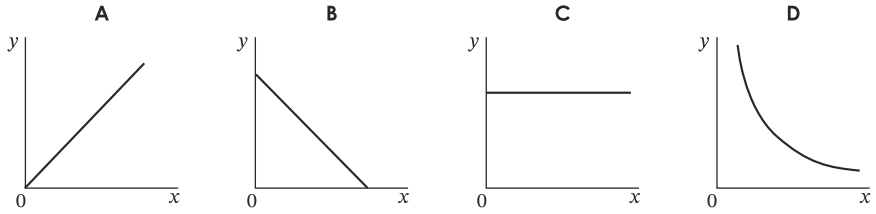
Key relations

Quantity	Meaning
Z = PV / nRT	compression factor; Z = 1 for an ideal gas
Z < 1	intermolecular forces dominate (moderate P, low T)
Z > 1	molecular volume dominates (very high P)
Van der Waals	$(P + n^2a / V^2)(V - nb) = nRT$
Near-ideal conditions	high temperature and low pressure

Warm Up

Regarding an ideal gas, choose the graph (A to D) that represents each relationship (a) to (c).



(a) The relationship between volume x and pressure y when the amount of substance and temperature of the gas are constant.

_____

(b) The relationship between the amount of substance x and pressure y when the temperature and volume are constant.

_____

(c) The relationship between pressure x and the product of pressure and volume y when the amount of substance and temperature of the gas are constant

_____

Explanation

By rearranging the ideal gas equation, PV = nRT.

(a) Solving the ideal gas equation for pressure to obtain an equation in terms of y, $P = \frac{nRT}{V}$

When the amount of substance and temperature of the gas are constant, nRT is a constant, so the pressure P is inversely proportional to the volume ***V****.*

Therefore, the graph showing the relationship between x and y is D.

(b) Solving the ideal gas equation for pressure to obtain an equation in terms of y, $P = \frac{nRT}{V}$

When the temperature and volume are constant, $\frac{RT}{V}$ *is a constant, so the amount of substance n is directly proportional to the pressure P.*

Therefore, the graph showing the relationship between x and y is ***A****.*

(c) When the amount of substance and temperature of the gas are constant, the right side of PV = nRT remains constant. The left side *PV* is *y*.

Regardless of the value of pressure P, the product of pressure and volume PV is always constant, so the graph showing the relationship between x and y is ***C****.*

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Try

Choose the correct answer:

1. *Which statement correctly describes an ideal gas?*

A. Gas molecules have finite volume and attractive forces.

B. Gas molecules have zero volume and no intermolecular forces.

C. Gas molecules have large volume but no attractive forces.

D. Gas molecules occupy half of the container volume.

Answer: _____

2. *Under which conditions will a real gas behave most like an ideal gas?*

A. Low temperature and high pressure.

B. High temperature and low pressure.

C. Low temperature and low pressure.

D. High temperature and high pressure.

Answer: _____

3. *Regarding ideal gases and real gases, select all the correct statements from (i) to (iv) below.*

(i) "A gas where the molecules themselves have no volume, and the molecules move freely without intermolecular forces

acting between them" is a real gas.

(ii) For a real gas, the ideal gas equation holds strictly at any temperature, volume, and pressure.

(iii) As the temperature rises, the deviation of a real gas from an ideal gas becomes smaller.

(iv) Comparing hydrogen at 300 K and 1.0×10^5 Pa with hydrogen at 350 K and 4.0×10^4 Pa, the hydrogen at 300 K and 1.0×10^5 Pa is closer to an ideal gas.

Exercise

Regarding an ideal gas, choose the graph (A to E) that represents each relationship (a) to (e). You may choose the same letter multiple times.

Answer: _____

(a) The relationship between the amount of substance x and the volume y of a gas when the temperature and pressure are constant.

Answer: _____

(b) The relationship between the absolute temperature x and the volume y of a gas when the amount of substance and pressure are constant.

Answer: _____

(c) The relationship between the absolute temperature x and the pressure y of a gas when the amount of substance and volume are constant.

Answer: _____

(d) The relationship between the pressure x and the volume y of a gas when the amount of substance and temperature are constant.

Answer: _____

(e) The relationship between the pressure x and the product of pressure and volume y of a gas when the amount of substance and temperature are constant.

Answer: _____

Nature of Science

Scientific knowledge evolves over time.

When observations could not be fully explained by the Ideal Gas Model, scientists developed improved models such as the Van der Waals Equation.

Reflect and Grow

Complete:

✓ One idea that changed my thinking

.....

✓ One real-life application I discovered

.....

✓ One question I still want to investigate

.....

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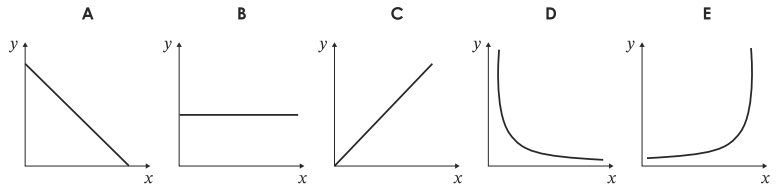

Answer: _____

Challenge Your Thinking

A real gas is compressed to an extremely high pressure while its temperature remains high.

Predict:

• Will the gas behave more ideally or less ideally?

_____

• Which factor is likely to dominate: intermolecular forces or molecular volume?

_____

• Will Z most likely be greater than 1, less than 1, or close to 1?

_____

Justify your answer using particle-level reasoning and evidence from the lesson.

_____

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1-8 — Properties of Solutions

✨ Engaging Introduction

A student vigorously shakes a bottle of water and cooking oil. For a short time the liquids appear mixed, but a few minutes later two separate layers form again. Many people assume that stirring longer should keep them mixed.

Let›s explore how substances dissolve, and what factors decide whether they stay dissolved or separate from a solution.

❓ **Guiding question:** Why do some substances dissolve easily while others do not, and how can scientists predict and control solubility?

Exploration

Predict Before You Learn

Without conducting an experiment, predict what would happen if you add the following substances to water:

- Table salt
- Sugar
- Vegetable oil
- Candle wax

For each substance:

- Will it dissolve? _____
- Why do you think so? _____
- What evidence supports your prediction?

📌 **Point!**

1. Dissolution

(a) **Dissolution:** The phenomenon where a substance dissolves uniformly in a solvent.

(b) **Many ionic crystals and dissolution:**

Ionic crystals readily dissolve in water and are largely insoluble in non-polar solvents.

(c) **Polarity and dissolution:**

Substances with similar polarity tend to dissolve in one another.

- Polar molecules readily dissolve in polar solvents. (Because the positive and negative charges attract each other).
- Non-polar molecules readily dissolve in non-polar solvents.
- Substances composed of polar molecules and non-polar molecules do not readily dissolve in each other.

(d) **Solubility:** The maximum amount of a solute that dissolves in a given amount of solvent. In the case of solids, it is often expressed as the maximum mass of solute that dissolves in 100 g of solvent.

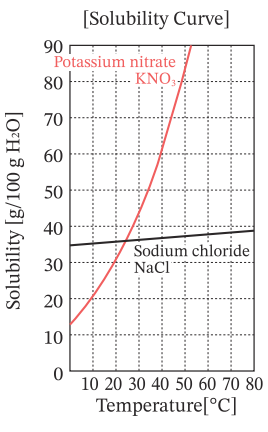

Fig 1.8.1 Solubility Curve

⭐⭐ **structure of science**

Key Fact :

The solubility of a substance depends on the nature of the solute and solvent — substances with similar polarity tend to dissolve in one another.

Key Concepts:

- Dissolution
- Solubility
- Solvent and solute
- Polarity
- Ionic crystals
- Concentration
- Molarity
- Molality
- Recrystallization

Scientific law:

Henry›s law (gas solubility ∝ gas

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(e) **Solubility curve:** A curve showing how solubility varies with temperature (Figure 1.8.1).

(f) **Recrystallization:** Recovering a dissolved substance as solid crystals by utilizing the difference in solubility due to temperature.

2. Concentration

(a) **Percentage by mass:** A concentration expressing the ratio of the mass of the solute to the mass of the solution.

Percentage by mass (%) = (mass of solute (g) / mass of solution (g)) × 100.

(b) **Molarity (molar concentration):** A concentration expressing the amount of solute dissolved in 1 L of solution in terms of amount of substance (mol).

Molarity [mol/L] = Amount of Substance of Solute (mol) / Volume of Solution (L).

(c) **Molality:** A concentration expressing the amount of solute dissolved in 1 kg of solvent in terms of amount of substance (mol).

Molality (mol/kg) = Amount of Substance of Solute (mol) / Mass of Solvent (kg).

Example — Molality of an aqueous solution in which 2.0 g of sodium hydroxide is dissolved in 23.0 g of water (NaOH = 40)

The amount of substance of sodium hydroxide is $\frac{2.0\ \text{g}}{40\ \text{g/mol}} = 0.050\ \text{mol}$

Since the mass of water is 23.0 g = 0.023 kg,

the molality is: $\frac{0.050\ \text{mol}}{0.023\ \text{kg}} = 2.17 \approx 2.2\ \text{mol/kg}$

3. Solubility of gases

Henry's law: At a constant temperature, the amount of substance and mass of a gas that dissolve in a given amount of solvent are directly proportional to the pressure of the gas.

• When considering the solubility of a gas, Henry's law is used.

Equation box

Concentration	Definition
Percentage by mass [%]	(mass of solute / mass of solution) × 100
Molarity [mol/L]	amount of solute [mol] / volume of solution [L]
Molality [mol/kg]	amount of solute [mol] / mass of solvent [kg]
Henry›s law	dissolved amount (mol or g) ∝ gas pressure

Chemistry in Everyday Life

Why Do Soft Drinks Fizz?

Soft drinks contain carbon dioxide dissolved under high pressure.

When the bottle is opened:

• Pressure decreases.

• Gas solubility decreases.

• Carbon dioxide escapes as bubbles.

This is a direct application of Henry's Law.

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Appreciating Scientists

William Henry discovered an important relationship between gas pressure and gas solubility.

His work continues to influence environmental science, medicine, and industry today.

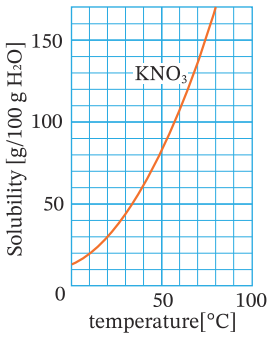
Warm Up

Answer the following questions.

(a) Among the following, choose all that dissolve in water but are largely insoluble in hexane:

A Naphthalene · B Glucose · C Potassium chloride.

(b) The figure on the right is the solubility curve of potassium nitrate KNO3.



Answer the following questions.

(i) When an aqueous solution saturated with potassium nitrate in 50 g of water at 50°C is cooled to 20°C, how many grams of crystals will crystallize out?

(ii) When 100 g of a saturated aqueous solution of potassium nitrate at 60°C is cooled to 20°C, how many grams of crystals will crystallize out?

(c) At 20°C and 1.0×10^5 Pa, 125 mL of oxygen dissolves in 1.0 L of water, converted to the volume at 0°C and 1.0×10^5 Pa.

What is the mass of oxygen in grams that dissolves in 1.5 L of water at 20°C and 2.0×10^5 Pa? Assume the volume of 1 mol of gas at 0°C and 1.0×10^5 Pa is 22.4 L. (O = 16)

Explanation

(a) Water is a polar solvent, and hexane is a non-polar solvent.

A. Since naphthalene is a non-polar molecule, it is largely insoluble in water and readily dissolves in hexane.

B. Since glucose is a polar molecule, it readily dissolves in water and is largely insoluble in hexane.

C. Since potassium chloride is an ionic crystal, it readily dissolves in water and is largely insoluble in hexane.

From the above, **B** and **C**.

(b) (i) From the figure, 84 g of potassium nitrate dissolves in 100 g of water at 50°C, so 42 g dissolves in 50 g of water.

Also, 30 g dissolves in 100 g of water at 20°C, so 15 g dissolves in 50 g of water. Therefore, the mass of crystals that crystallize out is 42−15 = 27 g..

(ii) From the figure, 108 g of potassium nitrate dissolves in 100 g of water at 60°C to form a saturated solution. The mass of this solution is 108 g+100 g = 208 g.

When this solution is cooled to 20°C, the mass of the precipitate is 108 g−30 g = 78 g.

Let x be the mass in grams of the precipitate formed from 100 g of the saturated solution.

Be a Global Citizen

Understanding solubility helps address global challenges such as water purification, ocean conservation, sustainable agriculture, and pollution control. Chemistry provides tools for making informed decisions about resources and environmental stewardship.

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We can set up the following proportion: 100 g : x [g] = 208 g : 78 g

x = 37.5 ≈ 38 g Answer: 38 g

(c) Since only the pressure and volume of the dissolved gas are known, first calculate the moles of gas to apply Henry's Law.

At 0°C and 1.0×10^5 Pa, 1 mol of gas occupies 22.4 L.

Let x be the moles of 125 mL (0.125 L) of oxygen:

1 mol : 22.4 L = x [mol] : 0.125 L

$x = 5.580\times10^{-3} \approx 5.58\times10^{-3}$ mol

According to Henry's law, the solubility of a gas at a constant temperature is directly proportional to its partial

pressure. Let y be the moles of oxygen dissolved in 1.0 L of water at 20°C and 2.0×10^5 Pa:

1.0×10^5 Pa : 5.58×10^{-3} mol = 2.0×10^5 Pa : y [mol]

$y = 1.11\times10^{-2}$ mol

Let z be the moles of oxygen dissolved in 1.5 L of water:

1.0 L : 1.11×10^{-2} mol = 1.5 L : z [mol]

$z = 1.66\times10^{-2}$ mol

Thus, the required mass of oxygen is: 1.66×10^{-2} mol × 32 g/mol = 0.531 g ≈ Answer: 0.54 g

Try

Choose the correct answer:

1. Glucose dissolves readily in water but is largely insoluble in hexane. Which explanation best accounts for this?

A. Glucose and water are non-polar.

B. Water and glucose have similar polarity.

C. Hexane and water form an ionic solvent.

D. Water contains ions.

Answer: _____

2. A student cools a saturated solution of potassium nitrate and observes crystals forming. Which process is occurring?

A. Neutralization B. Sublimation

C. Recrystallization D. Ionization

Answer: _____

Answer on the Following Questions

3. The figure shows the relationship between the solubility of potassium nitrate KNO_3 and temperature. Answer the following questions.

(a) How many grams of potassium nitrate can dissolve in 500 g of water at 50°C? Answer with two significant figures.

_____

(b) When a solution of 80 g of potassium nitrate dissolved in 100 g of water at 60°C is

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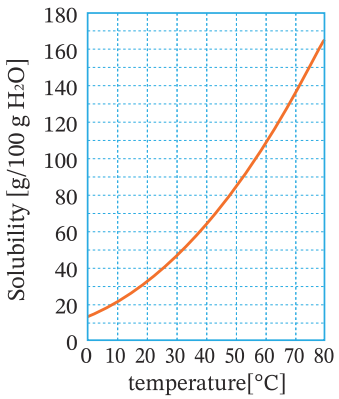
cooled to 20°C, how many grams of potassium nitrate crystals will be obtained?
Answer with two significant figures.

_____

(c) When an aqueous solution of 10 g of potassium nitrate dissolved in 50 g of water at 30°C is cooled, at what temperature do the crystals begin to crystallize out?

_____



(d) When 100 g of a saturated solution at 50°C is cooled to 20°C, how many grams of potassium nitrate crystals will be obtained? Answer with two significant figures

_____

Experimental Investigation

Which substance dissolves most effectively in water and which dissolves most effectively in a nonpolar solvent?

Materials

- Water
- Vegetable oil
- Salt
- Sugar
- Candle wax shavings

_____

Exercise

Answer on the Following Questions

1. Among (i) to (iii) below, choose all the substances that dissolve in hexane but do not dissolve in water.

(i) Potassium nitrate (ii) Hydrogen chloride (iii) Naphthalene

Answer: _____

2. The figure shows the solubility curves of KNO_3 and $NaNO_3$.

(a) 50 g of water was saturated with potassium nitrate at 70°C. How many grams of potassium nitrate are dissolved in the aqueous solution? Answer with two significant figures.

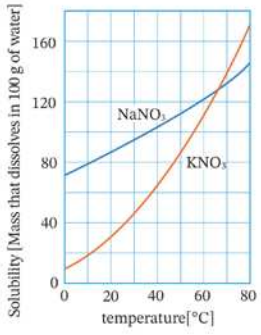
_____

_____

(b) When the solution from (a) is cooled to 20°C, how many grams of potassium nitrate will crystallize out? Answer with two significant figures.

_____

_____



Reflect and Grow

Complete:

✓ One idea that changed my thinking

.....

✓ One real-life application I discovered

.....

✓ One question I still want to investigate

.....

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(c) 50 g of sodium nitrate and 20 g of potassium nitrate were dissolved in 50 g of water at 80°C. When this solution is cooled, which substance crystallizes out first? Answer with its chemical formula.

_____

_____

Challenge Your Thinking

A diver descends to a great depth where pressure is much higher than at the surface. Without calculations:

• Predict what happens to the amount of nitrogen dissolved in the diver›s blood.

_____

• Predict what might happen if the diver ascends too quickly.

_____

• Explain your reasoning using Henry›s Law.

_____

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1-9 — Boiling Point Elevation and Freezing Point Depression

✨ Engaging Introduction

During winter, lakes in cold regions may freeze while nearby seawater often stays liquid at the same temperature. Both contain water, yet they behave differently. Scientists discovered that dissolved substances can change the temperatures at which liquids freeze and boil — with important consequences for oceans, climate, food preservation, and many industrial processes.

Let's explore how dissolved particles can dramatically alter the physical behaviour of liquids.

❓ Guiding question: How can dissolved particles change the temperature at which a liquid boils or freezes?

Exploration

Imagine adding increasing amounts of salt to water.

Predict what will happen to:

• The boiling point.

• The freezing point.

• The vapor pressure.

Explain your reasoning before looking at the graphs.

_____

Point!

1. Vapour-pressure lowering and boiling point elevation

(a) **Vapour-pressure lowering:**

The phenomenon where the vapour pressure of a solution in which a non-volatile substance is dissolved in a solvent becomes lower than the vapour pressure of the pure solvent. (Figure on the right 1.9.1)

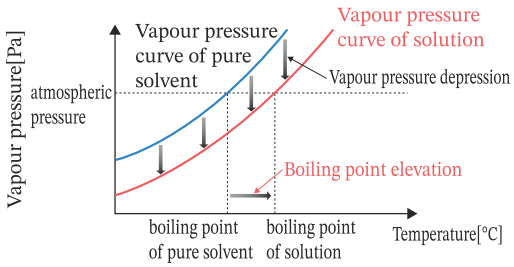

Figure 1.9.1 vapour pressure lowering curve

Reason: Because solute particles at the liquid surface inhibit the evaporation of solvent molecules.

(b) Boiling point elevation: The phenomenon where the boiling point of a solution becomes higher than the boiling point of the pure solvent.

(c) **Molal boiling point elevation constant:**

The boiling point elevation when the molality of the solution is 1 mol/kg.
It is represented by the symbol K_b.

structure of science

Key Fact :

Boiling point elevation and freezing point depression depend on the number of dissolved particles in a solution, not on the type of solute.

Key Concepts:

- Boiling point - elevation
- Freezing point depression
- Supercooling ·
- Non-volatile solute ·
- Cooling curve.

Scientific law:

Boiling Point Elevation $\Delta t = Kbm$

Freezing Point Depression $\Delta t = Kfm$

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Think Like a Chemist

A chemist wants to recover pure crystals from a dissolved substance.

Instead of evaporating all the solvent, the chemist cools the solution.

Reflection

Why can cooling be an effective purification method?

_____

Connect your answer to solubility and crystallization.

_____

2. Freezing point depression

(a) **Cooling curve:** A graph showing the relationship between the temperature of a substance and the cooling time. (Figure on the right 1.9.2)

(b) **Freezing point:** The temperature at which the solvent in a solution begins to freeze.

(c) **Freezing point depression:**

The phenomenon where the freezing point of a solution in which a non-volatile substance is dissolved in a solvent becomes lower than the freezing point of the pure solvent.

(d) **Molal freezing point depression constant:** The freezing point depression when the molality of the solution is 1 mol/kg. It is represented by the symbol Kf.

(e) **Supercooling:** The phenomenon where the temperature of a liquid falls below its freezing point while remaining in a liquid state as it is cooled.

- When freezing begins in a supercooled state, the temperature rises.
- The cooling curve of a solution shows that the temperature continues to fall even as freezing progresses.

Reason: Because only the solvent freezes, the concentration of the solution increases, and the freezing point depression becomes larger.

- When supercooling occurs, the freezing point is taken as the temperature at the point where the horizontal plateau line (extended to the left) intersects the original cooling curve. (see Figure above 1.9.2)

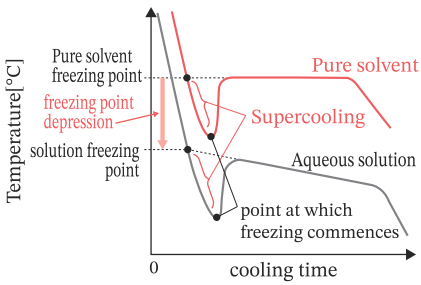

Figure 1.9.2. Freezing point depression

Graph Literacy

Examine the Freezing point depression graph carefully.

Identify:

- Where super-cooling occurs?

_____

- Where freezing begins?

_____

- The actual freezing point.

_____

- Evidence that freezing is occurring.

_____

Explain

Why does the temperature rise slightly after super-cooling?

_____

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3. Magnitude of boiling point elevation and freezing point depression

(a) Magnitude of boiling point elevation and freezing point depression

(i) It is independent of the type of solute.

(ii) It is directly proportional to the molality of the solution.

Note: When the solute is an electrolyte, the molality of the solution is considered to be directly proportional to the number of particles in the solution.

Example: Sodium chloride NaCl ionizes into Na^+ and Cl^- in aqueous solution, and the number of particles in the solution doubles.

⇒ The molality of the solution is considered to be doubled.

(b) Magnitude of molal boiling point elevation and molal freezing point depression constants

(i) They take values determined by the solvent, regardless of the type of solute.

(ii) It serves the proportionality constant K relating the magnitude of the boiling point elevation or freezing point depression and the molality.

• When the molality of the solution is m [mol/kg] and the magnitude of the boiling point elevation or freezing point depression is Δt,

Δt = Km (K is the molal boiling point elevation constant Kb or the molal freezing point depression constant Kf), (m: molality of dissolved molecules and ions)

📦 Equation box

Quantity	Relation
Boiling point elevation	$\Delta t = K_b \cdot m$
Freezing point depression	$\Delta t = K_f \cdot m$
Electrolyte solute	multiply molality by the number of ions per formula unit

🚗 Chemistry around us

Antifreeze in Car Radiators

In cold climates, water inside a car's radiator could freeze when temperatures drop below 0°C. If this happens, the expanding ice may damage the cooling system and engine components.

To prevent this problem, a substance such as ethylene glycol is added to the radiator water. The dissolved particles lower the freezing point of the solution, allowing it to remain liquid at temperatures where pure water would freeze.

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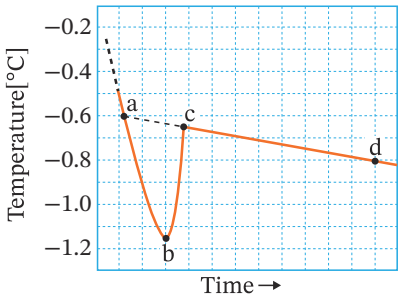
Warm Up

Answer the following questions.

(a) The figure shows the temperature change when a solution of non-electrolyte A dissolved in 100 g of water is cooled. Answer the following questions.



(i) What is the cooling state between a and b in the figure called?

(ii) At which point, a, b, or c, do crystals begin to form?

(iii) Which point's temperature from a to d is the freezing point of the solution?

(b) Answer the following questions. Assume the freezing point of water is 0°C, and the molal freezing point depression constant of water is 1.85 K·kg/mol.

(i) Find the freezing point of an aqueous solution in which 11.7 g of sodium chloride NaCl (formula mass 58.5) is dissolved in 500 g of water. Assume sodium chloride is completely ionized.

(ii) The difference in freezing point between an aqueous solution of 7.5 g of a certain non-volatile non-electrolyte dissolved in 250 g of water and pure water was 0.30°C. At this time, find the relative molecular mass of the non-electrolyte as an integer.

Explanation

(a) (i) Supercooling

(ii) When freezing begins in a supercooled state, the temperature rises, so the lowest temperature point is the point where freezing begins and crystals begin to form. b

(iii) a

The freezing point is where line segment cd intersects the temperature axis when extended to the left.

(b) (i) When finding the freezing point of an aqueous solution, first find the magnitude of the freezing point depression of the aqueous solution.

Since the freezing point of water is 0°C, the freezing point of an aqueous solution can be determined once the magnitude of the freezing point depression is known.

If the required magnitude of the freezing point depression of the aqueous solution is Δt_f, the molal freezing point depression constant is K_f, and the molality of the solution is m [mol/kg], the following equation applies: $\Delta t_f = K_f m$

Therefore, first find the molality m of the solute particles.

The amount of substance of the dissolved sodium chloride is $\frac{11.7\ \text{g}}{58.5\ \text{g/mol}} = 0.200\ \text{mol}$, and the mass of water is 500 g = 0.500 kg, so

$$m = \frac{0.200\ \text{mol}}{0.500\ \text{kg}} = 0.400\ \text{mol/kg}$$

Here, the sodium chloride NaCl aqueous solution ionizes to produce Na^+ and Cl^-, and the number of particles doubles, so the molality is also considered to be doubled. Therefore,

0.400 mol/kg × 2 = 0.800 mol/kg

Thus, the magnitude of the freezing point depression is:

Δt_f = 1.85 K.kg/mol × 0.800 mol/kg = 1.48 K

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Since the freezing point of water is 0°C, the required freezing point of the aqueous solution is:

0 − 1.48 = −1.48°C

(ii) Since the molal freezing point depression constant is given, the relative molecular mass is found using the molality m [mol/kg].

Let the molar mass of the non-electrolyte be M [g/mol], the molality is: $\frac{\frac{7.5}{M}\,[\text{mol}]}{0.250\ \text{kg}}$

Also, the difference from the freezing point of pure water is the magnitude of the freezing point depression of the aqueous solution.

If the magnitude of the freezing point depression is Δtf and the molal freezing point depression constant is Kf, then Δtf = Kfm holds, so

$$0.30\ \text{K} = 1.85\ \text{K·kg/mol} \times \frac{\frac{7.5}{M}\,[\text{mol}]}{0.250\ \text{kg}}$$

Solving this gives M = 185 g/mol. Therefore, the relative molecular mass is 185.

Think Critically

Evidence or Assumption?

Two containers are placed in a freezer:

- Container A contains pure water.
- Container B contains salt water.

Container A freezes first.

A student concludes:

«The freezer cooled Container A more effectively.»

Is this conclusion supported by evidence? .....

What alternative explanation could account for the observation? .....

Try

Choose the correct answer:

1. A scientist doubles the molality of a solution while keeping the solvent unchanged. What happens to the boiling point elevation?

A. It remains unchanged.
B. It doubles.
C. It is halved.
D. It becomes zero.

Answer: _____

2. A student cools a saturated solution of potassium nitrate and observes crystals forming. Which process is occurring?

A. Neutralization
B. Sublimation
C. Recrystallization
D. Ionization

Answer: _____

Be a Global Citizen

Climate, Ice, and Transportation

Countries around the world use salts to reduce accidents caused by icy roads.

However, excessive use of road salts can affect soil quality, freshwater ecosystems, and drinking-water supplies.

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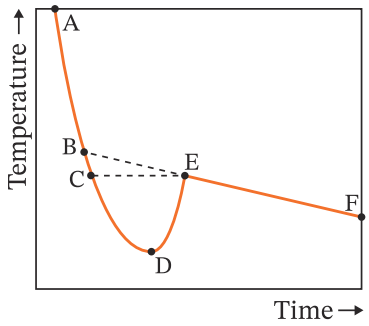
Solve the Following Questions

3. The figure is a cooling curve showing the relationship between cooling time and temperature when a dilute aqueous solution of sucrose $C_{12}H_{22}O_{11}$ is cooled. Answer the following questions.



(a) What is the phenomenon where the temperature drops while remaining a liquid

even after passing the freezing point, as shown in the figure? Write its name.

_____

(b) Which point's temperature from A to F in the figure is the freezing point?

_____

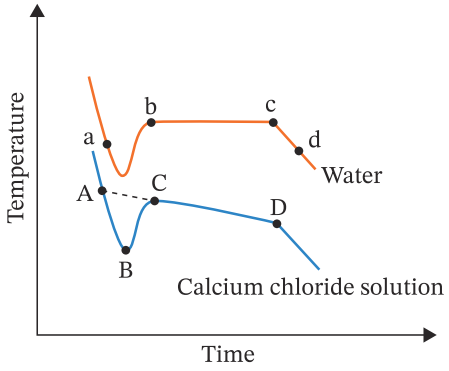
(c) Explain why the straight line EF in the figure slopes downward to the right

_____

Exercise

Answer on the Following Questions

The figure on the right is a cooling curve showing the relationship between cooling time and temperature when water and a calcium chloride aqueous solution are slowly cooled. Answer the following questions.



(a) What is the phenomenon occurring to the water at a?

_____

(b) Which point (A to D) in the figure represents the freezing point of the calcium chloride aqueous solution?

_____

(c) Where does the freezing of the calcium chloride aqueous solution begin? Choose from A to D in the figure.

_____

(d) In the range from b to c, the temperature is constant despite being cooled. Briefly explain the reason.

_____

(e) In the range from C to D, the temperature gradually drops. Briefly explain the reason

_____

Reflect and Grow

Complete:

✓ One idea that changed my thinking

.....

✓ One real-life application I discovered

.....

✓ One question I still want to investigate

.....

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Grand Challenge

Designing an Eco-Friendly De-Icer

Your city wants to reduce winter road accidents while minimizing environmental damage.

You have access to:

- Sodium chloride
- Calcium chloride
- Sugar
- Sand

Using your understanding of freezing point depression:

- Which material would you recommend? .....
- What evidence supports your choice? .....
- What environmental trade-offs should be considered? .....

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1-10 — Osmotic Pressure

✨ Engaging Introduction

A cucumber is placed in a concentrated salt solution and left for several hours. Later it becomes noticeably smaller and softer. Nothing seems to have been taken from the cucumber, yet its size has changed. **Where did the water go?**

In this lesson we will examine how careful observations of water movement in living organisms led scientists to develop models and explanations for osmosis and osmotic pressure.

❓ **Guiding question:** How and why does a solvent move across a semipermeable membrane, and how can scientists measure the pressure this produces?

Exploration

Investigate Water Movement

Imagine a U-tube separated by a semipermeable membrane.

One side contains pure water.

The other side contains a glucose solution.

Without studying the lesson:

• Predict the direction of water movement.

_____

• Predict what will happen to the liquid levels.

_____

• Explain your reasoning.

_____

Point!

Osmosis and osmotic pressure

(i) **Semipermeable membrane:**

A membrane with tiny pores that lets small solvent molecules (e.g. water) pass but blocks large solute molecules (e.g. sucrose) — for example, cellophane or an animal bladder membrane.

(ii) **Osmosis:**

The phenomenon where solvent molecules move through a semipermeable membrane into the solution side when a solvent and pure water (or solutions of different concentrations) are separated by the membrane.

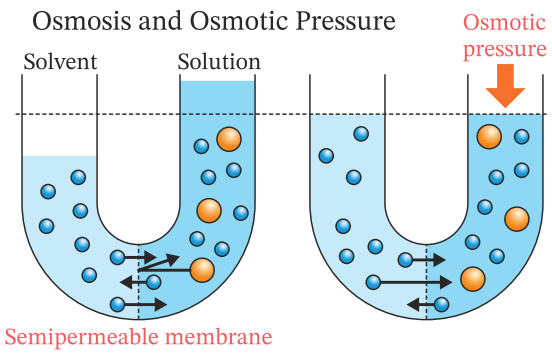

Figure 1.10.1 Osmosis and Osmotic Pressure

structure of science

Key Concepts:

- Semipermeable membrane
- Osmosis
- Osmotic pressure
- Reverse osmosis
- Concentration ·
- Solvent and solute.

Scientific law:

van't Hoff's law for dilute solutions ($\pi = cRT$).

Scientific Models

No scientist can directly observe billions of water molecules moving through a membrane at the same time. Instead, scientists use diagrams, models, and mathematical relationships to explain and predict what is happening.

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Mechanism: Why does it occur?

Water molecules are constantly moving in both directions through the pores of the semipermeable membrane.

However, large "solute molecules" that cannot pass through the pores are present on the solution side, physically obstructing the return of water molecules to the pure water side. As a result, the number of water molecules moving from the "pure water → solution" side exceeds the number moving in the opposite direction, leading to a net movement of water into the solution.

(iii) **Osmotic pressure:**

- When osmosis occurs in a U-tube, the liquid level on the solution side rises. Osmosis stops when the pressure exerted by the difference in the height of the liquid levels (the hydrostatic pressure of the water column) balances the osmotic pressure.
- Therefore, osmotic pressure is equal to **the pressure that must be applied to the solution side to prevent osmosis (i.e., to maintain the liquid levels on both sides at the same height).**

Natural Phenomenon

Plant cells contain water that generates internal pressure against the cell walls, When water is lost, the cells become less rigid and the plant begins to wilt. Osmosis plays a crucial role in maintaining plant structure and survival.

(iv) van't Hoff's Law:

For dilute solutions, the osmotic pressure π [Pa] is proportional to the molar concentration c [mol/L] of the solution and the absolute temperature T [K], regardless of the type of solvent or solute.

$$\pi = cRT$$

(R: Molar gas constant. Since $c = \frac{n}{V}$, the relationship can also be expressed as πV = nRT. This equation has the same form as the ideal gas equation of state.)

Nature of Science

Scientific explanations are accepted because they are supported by evidence.

However, if new evidence emerges, scientists may revise or improve existing models.

Equation box

Quantity	Relation
Van't Hoff's law	π = cRT
Equivalent form	πV = nRT (R = molar gas constant)

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Life Application

Reverse Osmosis-The Technology to Convert Saltwater into Fresh Water, What happens if pressure greater than the osmotic pressure is forcibly applied to the solution side?

Astonishingly, water molecules in the solution (the concentrated side) are forced through the semipermeable membrane and pushed out to the pure water (the dilute side), contrary to the natural direction of osmosis. This phenomenon is called reverse osmosis.

Reverse osmosis technology plays a vital role in supporting our daily lives, most notably in seawater desalination. By applying high pressure to seawater and passing it through a special semipermeable membrane (known as an RO membrane), solutes like salt are blocked, and only potable water (fresh water) is extracted. This chemical principle is applied in countries facing water scarcity, in water purification systems during disasters, and even for water recycling on the International Space Station (ISS).

An understanding of the invisible, microscopic phenomenon of water movement is connected to magnificent technology that solves global challenges.

Warm Up

Answer the following questions.

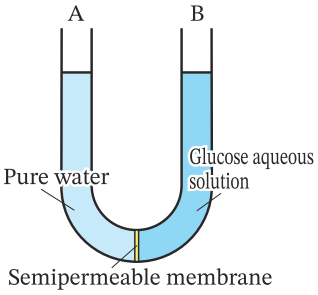
A As shown in the figure, the center of a U-tube is partitioned by a semipermeable membrane. Pure water is placed in A, and a glucose aqueous solution is placed in B at the same time so that both liquid levels are at the same height, and left at 27°C.

Assume the relative molecular mass of glucose is 180 and the gas constant is 8.3×10^3 Pa·L/(K·mol).

(a) After a while, which liquid level rises, A or B ?

(b) In the case of (a), write the name of the substance that moves through the semipermeable membrane.

(c) This glucose aqueous solution is made by dissolving 1.2 g of glucose $C_6H_{12}O_6$ to make 200 mL. What osmotic pressure (in Pa) must be applied to stop the level rising?



Explanation

(a) Since pure water permeates to the glucose aqueous solution side by osmosis, the liquid level on the glucose aqueous solution side rises. Therefore, **B**.

(b) Water

(c) When calculating the osmotic pressure, van't Hoff's law is used. Let the osmotic pressure be Π [Pa], from van't Hoff's law ΠV = nRT:

$$\Pi\,[Pa] \times 0.200\ L = \frac{1.2\ g}{180\ g/mol} \times 8.3\times10^3\ Pa\cdot L/(K\cdot mol) \times (27+273)\ K$$

● Convert the unit of volume to [L] and the unit of temperature to [K].

$$\Pi = \frac{\overset{6}{\cancel{1.2}}^{2}\ g \times 8.3\times10^3\ Pa\cdot L/(K\cdot mol) \times \overset{5}{\cancel{300}}\ K}{\underset{1}{\overset{3}{\cancel{180}}}\ g/mol \times \underset{1}{\cancel{0.200}}\ L}$$

$$= 8.3\times10^4\ Pa$$

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Think Critically

A student says: «The water moved because the glucose molecules pulled it through the membrane».

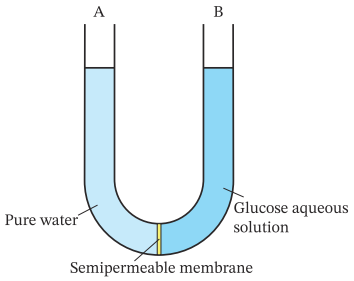
Evaluate the Claim

- Is this explanation fully accurate? .....
- What evidence supports or challenges it? .....
- How would you improve the explanation? .....

Try

. Read the following text and answer the questions below.

As shown in the figure, the center of a U-tube is partitioned by a semipermeable membrane. Pure water is placed in A , and a glucose aqueous solution is placed in B at the same time so that both liquid levels are at the same height, and left at 27°C. From the ((i) A / B) side to the ((ii) A / B) side, molecules of ((iii) water / glucose) pass through the semipermeable membrane, and the liquid level in ((iv) A / B) rises.



(a) Choose the appropriate letters or words for (i) to (iv) in the text from the brackets.

(b) This glucose aqueous solution is made by dissolving 1.8 g of glucose $C_6H_{12}O_6$ in water to make 300 mL. What is the pressure (osmotic pressure) in Pa applied to prevent the liquid level of this aqueous solution from rising? Calculate the osmotic pressure to two significant figures. Assume the gas constant R = 8.3×10^3 Pa·L/(K·mol). ($C_6H_{12}O_6$ = 180)

Answer: _____

Exercise

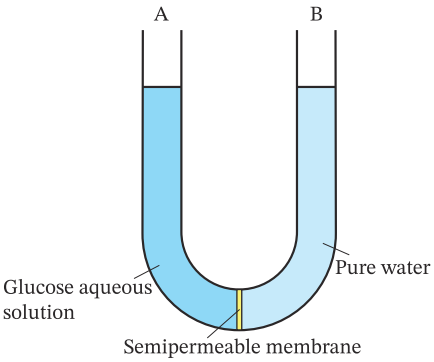
. As shown in the figure, the center of a U-tube is partitioned by a semipermeable membrane. A glucose aqueous solution is placed in A, and pure water is placed in B at the same time so that both liquid levels are at the same height, and left at 27°C. Answer the following questions.

(a) Which liquid level rises, A or B?

_____

(b) This glucose aqueous solution is made by dissolving 0.60 g of glucose $C_6H_{12}O_6$ in water to make 200 mL.

What is the pressure (osmotic pressure) in Pa applied to prevent the liquid level of this aqueous solution from rising? Calculate the osmotic pressure to two significant figures. Assume the gas constant R = 8.3×10^3 Pa·L/(K·mol). (C = 12, H = 1.0, O = 16)



_____

Challenge Your Thinking

A plant begins to wilt after being watered with a concentrated fertilizer solution.

Using your understanding of osmosis:

- Predict the direction of water movement. .....
- Explain why the plant loses rigidity. .....
- Suggest a solution to help the plant recover. .....

Reflect and Grow

Complete:

✓ One idea that changed my thinking

.....

✓ One real-life application I discovered

.....

✓ One question I still want to investigate

.....

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1-11 — Colloids

✨ Engaging Introduction

You shine a laser beam through two containers — one holds pure water, the other holds diluted milk.

What is your observation?

_____

What is your conclusion?

_____

In this lesson we will investigate the reason behind this, understand the meaning of colloids, and study their main properties, including hydrophilic colloids and salting out, and hydrophobic colloids and coagulation.

❓ Guiding question: How can tiny particles dispersed in a medium influence the behaviour of light, motion, and matter?

structure of science

Key Fact :

The unique properties of colloids arise from the intermediate size and charge of their particles.

Key Concepts:

- Colloidal particles
- Sol (colloidal solution)
- Hydrophilic colloid
- Hydrophobic colloid
- Protective colloid.

📌 Point!

1. Colloids

(a) **Colloidal particles:** particles about 10^{-9} m to 10^{-7} m in diameter — larger than ions and molecules; they cannot pass through a semipermeable membrane (e.g. cellophane) but can pass through filter paper.

(b) **Colloid:** a state in which colloidal particles are uniformly dispersed in another substance (or the substance itself).

(c) **Colloidal solution (sol):** a solution in which colloidal particles are dispersed in a liquid.

(d) **Gel:** a sol that has lost its fluidity. Example: hot milk with starch (sol) → chilled mahallabiya (gel).

🔬 Experimental Investigation

Materials

• Water • Milk • Salt solution • Starch solution • Laser pointer

Procedure

Shine the laser through each sample in a darkened room and observe whether the light path becomes visible.

What is your observation?.....

What is your conclusion?.....

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2. Properties of colloids

(a) **Tyndall effect:** The phenomenon where colloidal particles scatter light, making the path of the light visible.

(b) **Brownian motion:** The irregular motion of colloidal particles caused by the collision of particles of the dispersion medium with the colloidal particles.

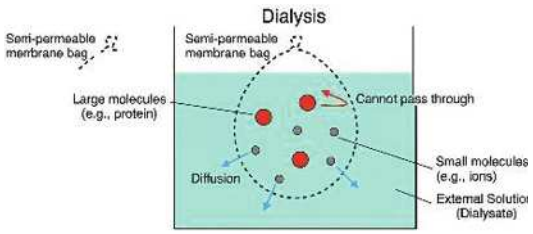

Figure 1.11.1 Dialysis Property

(c) **Dialysis:** The operation of separating and a colloidal solution using a semipermeable membrane, etc.(Because the colloidal particles are larger than the pores in the membrane).

(d) **Electrophoresis:** The phenomenon where charged colloidal particles move to one of the electrodes.

- Positively charged particles move to the cathode .
- Negatively charged particles move to the anode.

(e) **Hydrophilic colloids and salting out**

- **Hydrophilic colloid:** A colloid with a high affinity for water. (A large number of water molecules hydrate and disperse).
- **Salting out:** The phenomenon where precipitation occurs when a large amount of electrolyte is added to a hydrophilic colloid.

(f) **Hydrophobic colloids and coagulation**

- **Hydrophobic colloid:** A colloid with a low affinity for water. (Dispersed by the repulsive force between charges of the same sign). Example: Clay, sulfur, etc.
- **Coagulation:** The phenomenon where precipitation occurs when a small amount of electrolyte is added to a hydrophobic colloid.

An ion of the opposite sign to the charge of the colloidal particles and a higher valency is more likely to coagulate the colloid.

(g) **Protective colloid:** A hydrophilic colloid that makes it difficult for hydrophobic colloidal particles to coagulate when added to a hydrophobic colloid.

Warm Up

Answer the following questions.

(a) Read the text and answer.

A mixture in which particles of about 10^{-9} to 10^{-7} m are uniformly dispersed in a liquid is called a (A). When an aqueous solution of iron(III) chloride is added to boiling water, a (A) of iron(III) hydroxide forms. Placing this mixture in a cellophane bag immersed in distilled water removes the impurities and purifies it — this operation is called (B). When a small amount of electrolyte is added to a portion of the (A) and left to stand, precipitation occurs; this is called (C). Because this happens easily, the iron(III) hydroxide colloid is classified as a (D) colloid.

(i) Answer the words that correspond to A to D in the text.

(ii) The iron(III) hydroxide colloid is positively charged. Regarding the underlined part, which of the following aqueous electrolyte solutions (a to d) of the same molarity causes

Misconception Alert

«All mixtures that appear uniform are true solutions.»

Reality:

Some mixtures appear uniform but are actually colloids containing dispersed particles large enough to scatter light.

Interdisciplinary Connection

Hydrophobic colloids and coagulation

Colloids connect chemistry with:

- Biology (blood, proteins, cell membranes)
- Physics (light scattering, particle motion)
- Engineering (water treatment, pollution control)
- Medicine (dialysis).

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precipitation in the smallest amount?

a. NaCl · b. $Ca(NO_3)_2$ c. K_2SO_4 d. $CaCl_2$

(b) The following sentences describe characteristic phenomena exhibited by colloids. Identify the term closely related to each of the following phenomena.

(i) The path of light from car headlights can be seen from the side at night.

(ii) Soot can be removed by applying a high DC voltage inside a factory chimney.

(iii) Colloidal particles move irregularly when they collide with the surrounding solvent molecules.

Explanation

(a) (i) **A:** colloid (sol)

B: Small molecules and ions in the colloidal solution of iron(III) hydroxide pass through the cellophane membrane into the water. On the other hand, the colloidal particles of iron(III) hydroxide cannot pass through the cellophane membrane and remain in the bag, so the purity increases. The operation of separating a colloidal solution in this way is called dialysis. Dialysis.

C: The phenomenon where precipitation occurs when a small amount of electrolyte is added is coagulation.

Coagulation.

D: Hydrophobic

(ii) As it is a positively charged colloid, the electrolyte containing an anion with the highest ionic charge is the most

effective. Among **a** to **d**, the sulfate ion SO_4^{2-} has the largest valency. Therefore, **c**.

(b) (i) Colloidal particles in the air scatter light, making the path of light visible. Tyndall effect.

(ii) Colloidal particles of soot are attracted to the electrodes and are no longer emitted from the chimney.

Electrophoresis.

(iii) Brownian motion

Global Context

explanation

Colloidal chemistry plays an important role in Water purification, Air pollution control, Food production, Pharmaceutical industries.

Understanding colloidal systems helps scientists develop sustainable technologies for modern societies.

Try

Choose the correct answer:

1. A beam of light becomes visible when it passes through a colloidal solution. Which property is being observed?

A. Brownian motion

B. Electrophoresis

C. Dialysis

D. Tyndall effect

Answer: _____

2. A colloidal solution is placed in an electric field and its particles move toward the anode. What can be concluded?

A. The particles are positively charged.

B. The particles are neutral.

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C. The particles are negatively charged.

D. The particles contain no water.

Answer: _____

3. Among the following descriptions about colloids from A to E, choose all that are correct.

A. Because colloidal particle diameter is about 10^{-3} m, they cannot pass through filter paper.

B. The absorption of light by a colloid is the Tyndall effect.

C.Brownian motion occurs because solvent molecules in thermal motion collide irregularly with the colloidal particles.

D. Adding a large amount of electrolyte to egg-white solution causes no precipitation.

E. A colloid that has lost its fluidity, like chilled mahallabiya, is called a sol.

Answer: _____

Exercise

Answer on the Following Questions

1. When a small amount of electrolyte is added to a colloidal solution of arsenic sulfide, colloidal particles gather and precipitate. Also, when two electrodes are immersed in this colloidal solution and (b)a DC voltage is applied, the colloidal particles gather on the anode side, so the color near the anode becomes darker.

(a) What are the phenomena of the underlined parts (a) and (b) called, respectively?

(b) Do the colloidal particles of arsenic sulfide carry a positive or negative charge?

(c) When the following aqueous electrolyte solutions from A to E are added to the colloidal solution, which one causes the coagulation described in (a) at the lowest molarity?

A. NaCl B. $MgCl_2$ C. $Al(NO_3)_3$ D. Na_2SO_4 E. KNO_3

Answer: _____

2. Match each of the following descriptions (i) to (v) with the correct phenomenon or operation (A to E).

(i) Strong light on a starch solution makes the light path bright. ·

(ii) When a DC voltage is applied to an iron

(III) hydroxide colloidal solution, the colloidal particles move to the cathode side.

(iii) Under an ultramicroscope, colloidal particles move irregularly.

(iv) A large amount of electrolyte added to starch-milk or gelatin causes precipitation.

(v) A small amount of electrolyte added to a sulfur colloid causes precipitation.

A. Salting out B. Coagulation C. Tyndall effect

D. Brownian motion E. Electrophoresis

Answer: _____

Challenge your thinking

A community suffers from muddy drinking water containing suspended colloidal particles.

Using concepts from this lesson to answer on this questions:

- Which colloidal properties could help remove these particles?.....
- Would filtration alone be sufficient?.....
- How might coagulation improve purification?.....

Support your proposal using scientific reasoning.

Reflect and Grow

Complete:

✓ One idea that changed my thinking

.....

✓ One real-life application I discovered

.....

✓ One question I still want to investigate

.....

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1-12 — Structure of Metallic Crystals

✨ Engaging Introduction

Look around you.

Steel bridges support enormous loads.

Airplanes made from metal travel thousands of kilometers.

Yet metals are made of tiny atoms separated by empty space.

In this lesson, we will explore how the three-dimensional arrangement of atoms inside metals determines their properties and performance.

❓ **Guiding question:** How does the arrangement of atoms inside a metal influence its properties and applications?

structure of science

Key Fact :

The properties of a crystalline solid depend on the regular arrangement of particles within its crystal lattice.

Key Concepts:

- Crystal
- Crystal lattice
- Coordination number
- Amorphous solid
- Metallic crystal
- Atomic radius ·
- Packing efficiency.

Point!

1. Crystals and amorphous solids

(a) **Crystal:** A solid in which the particles are arranged in a regular pattern.

(b) **Crystal lattice:** The regular arrangement structure of the particles in a crystal.

(c) **Unit cell:** The smallest repeating unit in a crystal lattice.

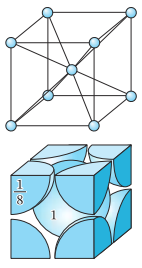
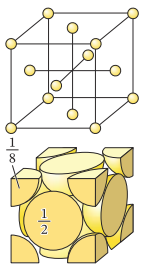
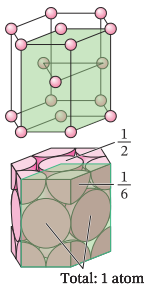
(d) **Coordination number:** The number of other particles present closest to a given particle in a crystal.

(e) **Amorphous solid:** A solid in which the arrangement of particles is not regular.

2. Structure of metallic crystals

(a) **Metallic crystal:** A crystal of many metal atoms held together by metallic bonds.

(b) **Structures of metallic crystals** — body-centred cubic (BCC), face-centred cubic (FCC), and hexagonal close-packed (HCP).

Name of structure	Body-centred cubic (BCC) lattice	Face-centred cubic (FCC) lattice	Hexagonal close-packed (HCP) structure
Unit cell			
Number of atoms in a unit cell	$\frac{1}{8}\times8+1=$ 2	$\frac{1}{8}\times8+\frac{1}{2}\times6=$ 4	$\left(\frac{1}{6}\times12+\frac{1}{2}\times2+3\right)\times\frac{1}{3}=$ 2
Coordination number	8	12	12
examples	Iron	Copper	Titanium

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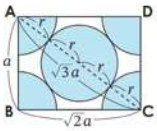
Structure	Atoms per unit cell	Coordination number
BCC	(1/8 × 8) + 1 = 2	8
FCC	(1/8 × 8) + (1/2 × 6) = 4	12
HCP	2	12

(c) Relationship between the edge length of a unit cell and the atomic radius Let the edge length of the unit cell be a and the atomic radius be r.

(i) Body-centred cubic lattice: In the plane ABCD of the figure on the right,

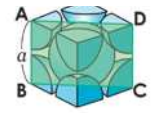


since AB = a, BC = $\sqrt{2}a$, we obtain, AC = $\sqrt{3}a$.

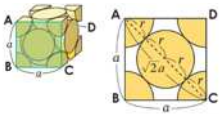
It can be calculated using Pythagoras' theorem.

Also, since AC = 4r, 4r = $\sqrt{3}a \Rightarrow r = \frac{\sqrt{3}}{4}a$

(ii)Face-centred cubic lattice: In the plane ABCD of the figure on the right, since AB = BC =a, AC = $\sqrt{2}a$.



Also, since AC = 4r, 4r = $\sqrt{2}a \Rightarrow r = \frac{\sqrt{2}}{4}a$.



(d) **Packing efficiency:** the percentage of the unit cell's volume occupied by atoms = **(volume of atoms in the unit cell) ÷ (volume of the unit cell)**.

Equation box — metallic structures at a glance

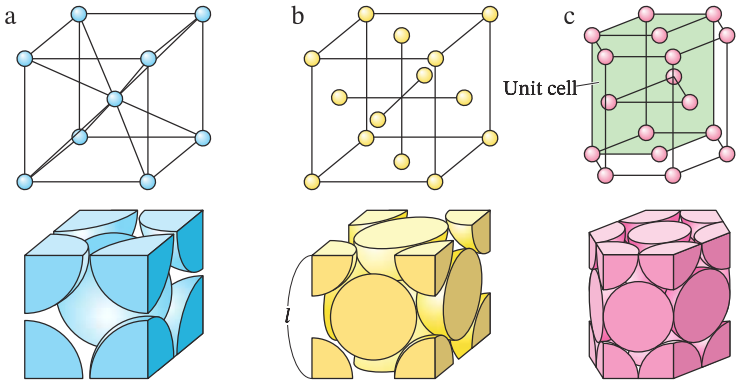
Structure	Atoms/cell	Coordination no.	r vs a
BCC	2	8	r = ($\sqrt{3}$ / 4) a
FCC	4	12	r = ($\sqrt{2}$ / 4) a
HCP	2	12	—

Life Application

Electrical Wiring & Devices: The face-centered cubic structure of copper allows electrons to flow freely. This provides the high electrical and thermal conductivity essential for household wiring, printed circuit boards (PCBs), and modern computing.

Warm Up

Answer the following questions.



(a) The figures show the structures of metallic crystals (a, b, c).

(i) What are the crystal structures of a and c called?

(ii) How many atoms are contained in the unit cell of a?

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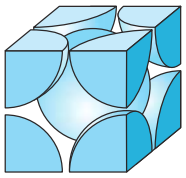
(iii) In b, letting the atomic radius be r and the edge length of the unit cell be l, express r in terms of l.

(b) The figure on the right represents the crystal lattice of iron. Letting the radius of an iron atom be r (cm) and the edge length of the crystal lattice in the figure be a (cm), answer the following questions



(i) Express r in terms of a.

(ii) Find the packing efficiency of iron atoms. You may leave square roots in your expression.

(iii) Find the density of iron atoms (g/cm3). Assume the Avogadro constant is NA (/mol). (Fe = 56)

Explanation

(a) (i) a: Body-centred cubic lattice / c: Hexagonal close-packed structure (ii) 2

(iii) The crystal structure of b is a face-centred cubic lattice. Therefore, $r = \frac{\sqrt{2}}{4}l$.

(b) (i) From the figure, the crystal lattice of iron is a body-centred cubic lattice. Therefore, $r = \frac{\sqrt{3}}{4}a$.

(ii) Packing efficiency = $\frac{\text{Volume of atoms in the unit cell}}{\text{Volume of the unit cell}}$

The number of atoms per unit cell is 2, and their volume is:

$$\frac{4\pi r^3}{3}\times 2 = \frac{4\pi\times\left(\frac{\sqrt{3}}{4}a\right)^3}{3}\times 2 = \frac{\sqrt{3}\pi a^3}{8}\,[\text{cm}^3]$$

Since the volume of the unit cell is a^3 [cm^3], the packing efficiency is:

$$\frac{\frac{\sqrt{3}\pi a^3}{8}}{a^3} = \frac{\sqrt{3}\pi}{8}$$

(iii) For the density of atoms, determine the density of the unit cell.

Density = $\frac{\text{Mass of the unit cell}}{\text{Volume of the unit cell}}$

First, since the molar mass of iron Fe is 56 g/mol, the mass of 2 iron atoms in the unit cell is:

$$\frac{56\ \text{g/mol}\times 2}{N_A\,[\text{/mol}]} = \frac{112}{N_A}\,[\text{g}]$$

Since the volume of the unit cell is a^3 [cm^3], the density is:

$$\frac{\frac{112}{N_A}\,[\text{g}]}{a^3\,[\text{cm}^3]} = \frac{112}{a^3 N_A}\,[\text{g/cm}^3]. \text{ Answer: } \frac{112}{a^3 N_A}\,[\text{g/cm}^3]$$

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Design Models by Home Materials

Body-Centered Cubic (BCC)

Materials

- 9 clay balls
- Toothpicks

Procedure

1. Construct a cube using 8 clay balls at the corners.
2. Connect corners using toothpicks.
3. Place one clay ball in the center of the cube.
4. Observe the arrangement from different directions.

Investigation

- Count corner atoms.

Answer: _____

- Identify the central atom.

Answer: _____

- Determine the coordination number.

Answer: _____

You can design model for Face-Centered Cubic (FCC) and Hexagonal Close-Packed (HCP), by the same procedure .

Try

Choose the correct answer:

1. A metallic crystal has a coordination number of 8. Which structure is most likely present?

A. FCC B. HCP

C. BCC D. Amorphous structure

Answer: _____

2. Both FCC and HCP structures have a coordination number of:

A. 6 B. 8

C. 10 D. 12

Answer on the following questions:

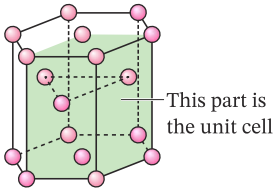
3. The figure shows the crystal structure of a certain metal. Answer the following questions.

(a) What is the crystal lattice of this metal called?

_____

(b) What is the total number of atoms contained in a unit cell?

_____



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(c) What is the coordination number of an atom in this lattice?

_____

(d) A solid with particles arranged regularly, like a metallic solid, is called a crystal. On the other hand, what is a solid with an irregular arrangement that is not crystallized called?

_____

Exercise

Answer on the Following Questions

(a) Name the three types of crystal lattice found in metallic crystals.

_____

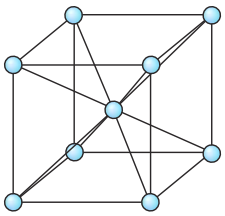
(b) Of the three types named in (a), which has the largest number of atoms in a unit cell?

_____

(c) Of the three types named in (a), which has the smallest coordination number? Also, write the coordination number of that lattice

_____

2. The figure on the right is the crystal structure of iron. Answer the following questions.



(a) In the iron crystal, what is the total number of atoms contained in a unit cell?

_____

(b) Assuming the edge length of the iron unit cell is a [cm], express the atomic radius of iron in terms of a. You may leave square roots in your expression.

_____

(c) Express the packing efficiency of the iron crystal lattice in terms of π.

_____

(d) Assuming the density of iron is d (g/cm^3), express the mass of one iron atom in terms of a and d.

_____

(e) Assuming the Avogadro constant is N_A (/mol), express the relative atomic mass of iron in terms of a, d, and N_A

_____

Think Critically

You are a materials engineer tasked with designing a metal for a lightweight electric vehicle.

Which crystal structure would you prefer?

• BCC • FCC • HCP

Answer: _____

Justify your choice using:

• Packing efficiency • Coordination number

Answer: _____

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1-13 — Structure of Ionic Crystals

✨ Engaging Introduction

Every grain of table salt contains billions of sodium and chloride ions. These ions carry opposite charges and are held together by powerful electrostatic attractions, so salt crystals grow into regular geometric shapes visible to the naked eye. In this lesson we explore how the arrangement of ions within a crystal determines its structure, stability, and physical properties.

❓ **Guiding question:** How does the arrangement of ions within a crystal determine its structure, stability, and physical properties?

Exploration

Using colored balls:

- Blue = Na^+
- Green = Cl^-

Arrange ions to satisfy the following condition:

Every ion should be surrounded by as many oppositely charged ions as possible.

Explore

- What pattern emerges?
- Why do ions not arrange randomly?

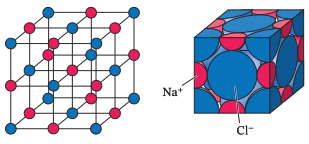
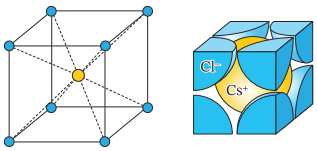
Point!

Structure of ionic crystals

(a) **Ionic crystal:** A crystal formed by cations and anions bound together by electrostatic forces (ionic bonds).

(b) **Coordination number:** the number of oppositely charged ions immediately surrounding a given ion in an ionic crystal.

(c) **Structural examples** — sodium chloride (NaCl) and caesium chloride (CsCl).

Ionic crystal	Sodium chloride NaCl	Caesium chloride CsCl
Unit Cell		
Number of ions in a unit cell	Na^+: $\frac{1}{4}\times12+1=$ 4 Cl^-: $\frac{1}{8}\times8+\frac{1}{2}\times6=$ 4	Cs^+: 1 Cl^-: $\frac{1}{8}\times8=$ 1
Coordination number	Na^+: 6 Cl^-: 6	Cs^+: 8 Cl^-: 8

structure of science

Key Fact :

The properties of ionic crystals depend on the regular three-dimensional arrangement of oppositely charged ions within the crystal lattice.

Key Concepts:

- Crystal
- Crystal lattice
- Cation
- Anion
- Ionic bond
- Unit cell
- Coordination
- number
- Ionic radius

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Equation box

Quantity	Relation
Density	formula units per cell × formula mass) ÷ (N_A × a^3
NaCl edge contact	$a = 2 \cdot r(Na^+) + 2 \cdot r(Cl^-)$
CsCl body diagonal	$\sqrt{3} \cdot a = 2 \cdot r(Cs^+) + 2 \cdot r(Cl^-)$

Real-World Application

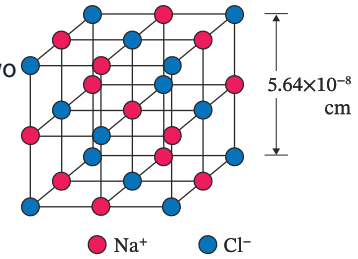
Salt in Food Preservation Salt makes water less available to microorganisms, which helps preserve food and prevent spoilage. Understanding ionic compounds and how they interact with water is essential in food science and preservation technologies.

Warm Up

The figure shows the NaCl crystal lattice, edge length 5.64×10^{-8} cm. (N_A = 6.0×10^{23} /mol; $5.64^3 = 179$; Na = 23, Cl = 35.5.)

(a) If the ionic radius of Na^+ is 1.16×10^{-8} cm, find the ionic radius r [cm] of Cl^- (three significant figures).

(b) Find the density of the NaCl crystal in g/cm³ (to two decimal places).

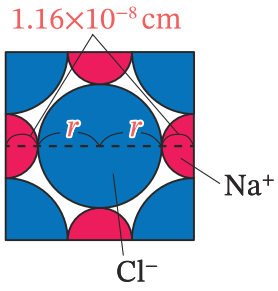


Explanation

(a) Along the edge where Na^+ and Cl^- are in contact, the edge length of the unit cell can be expressed as 1.16×10^{-8} cm $\times 2 + r$ [cm]$\times 2$.

Therefore, 1.16×10^{-8} cm $\times 2 + r$ [cm]$\times 2 = 5.64\times10^{-8}$ cm.

$r = 1.66\times10^{-8}$ cm



(b) Density is defined as: $\text{Density} = \dfrac{\text{Mass of unit cell}}{\text{Volume of unit cell}}$.

A unit cell of sodium chloride contains four Na^+ ions and four Cl^- ions, corresponding to four formula units of NaCl.

The mass of 4 NaCl units is: $\dfrac{58.5\ \text{g/mol}}{6.0\times10^{23}\ \text{/mol}} \times 4 = \dfrac{39}{10^{23}}$ g.

Also, since the volume of the unit cell is $(5.64\times10^{-8})^3\,\text{cm}^3$, the density of the crystal is:

$$\frac{\frac{39}{10^{23}}\text{g}}{(5.64\times10^{-8})^3\,\text{cm}^3} = 2.17\ \text{g/cm}^3$$

Nature of Science

Scientists developed crystal models using evidence from X-ray diffraction experiments, mathematical analysis, and repeated experimental observations.

Try

1. What is the primary force holding an ionic crystal together?

A. Hydrogen bonding B. Metallic bonding C. Electrostatic attraction between oppositely charged ions D. Van der Waals forces

Answer: _____

2. What is meant by the coordination number of an ion in an ionic crystal?

A. The number of electrons in the ion. B. The number of ions in the unit cell. C. The number

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of charged ions surrounding that ion. D. The number of bonds formed by the ion.

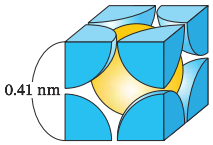
Answer: _____

3. The figure is the CsCl unit cell, with Cs^+ and Cl^- in contact. (Two significant figures; edge = 0.41 nm; $\sqrt{3} = 1.7$; N_A = 6.0×10^{23} /mol; Cl = 35.5, Cs = 133.)

(a) If the radius of Cl^- is 0.17 nm, find the radius of Cs^+ in nm.

(b) Find the volume of 1 mol of CsCl crystal in cm^3 ($1.0\ nm = 1.0 \times 10^{-7}\ cm$; $4.1^3 = 69$).

(c) Find the density of the CsCl crystal in g/cm^3.



Answer: _____

Exercise

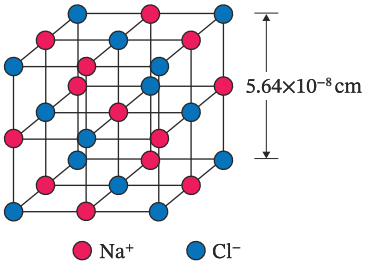
1. The edge of the unit cell of a NaCl crystal is 5.64×10^{-8} cm. Answer the following questions. Assume the Avogadro constant is 6.0×10^{23} /mol.

(a) What are the numbers of Na^+ and Cl^- in a unit cell, respectively?

(b) What is the total mass of NaCl in a unit cell in grams?

(c) What is the volume of the unit cell in cm^3? Assume $5.64^3 = 1.8 \times 10^2$.

(d) Calculate the density of the crystal in g/cm^3 to two decimal places.



Reflect and Grow

Complete:

✓ One idea that changed my thinking

.....

✓ One real-life application I discovered

.....

✓ One question I still want to investigate

.....

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Unit question

Read this case study, then Answer on the following questions

A humanitarian organization is designing portable cooling boxes to transport vaccines to remote communities where electricity is unavailable. The engineering team is considering three substances as cooling materials.

Data Table

Substance	Molar Mass (g/mol)	Heat of Fusion (kJ/mol)	Heat of Vaporization (kJ/mol)	Dominant Inter-molecular Force	Boiling Point (°C)
Water (H_2O)	18	6.0	41	Hydrogen bonding	100
Hydrogen Sulfide (H_2S)	34	2.4	18	Dipole–dipole / Van der Waals	-60
Hydrogen Bromide (HBr)	81	2.2	17	Dipole–dipole / Van der Waals	-67

The cooling box must maintain a low temperature for the longest possible time while remaining safe and practical for transport.

Part A — Data Analysis (Short Response)

Analyze the data provided and identify which substance would absorb the greatest amount of energy during a phase change from liquid to gas.

……

Support your answer using quantitative evidence from the table.

……

Part B — Scientific Explanation (Structured Response)

The boiling point of water is significantly higher than that of H_2S, even though water has a lower molar mass.

Explain this observation using intermolecular forces and particle interactions.

……

Part C — Evaluation (Extended Response)

An engineer argues:

"A substance with the largest molar mass should always have the highest boiling point because heavier molecules require more energy to separate."

Using evidence from the table and your understanding of intermolecular forces:

Evaluate the validity of this claim.

In your answer:

• discuss supporting evidence,

• identify limitations of the claim,

• compare molecular mass and intermolecular forces as factors affecting boiling point.

……

Part D — Essay Question (Extended Response)

To what extent is intermolecular force strength more important than molecular mass in determining the physical properties of substances?

Using evidence from the case study and examples from the unit, construct a well-reasoned scientific argument that:

• compares hydrogen bonding and Van der Waals forces,

• explains their effects on melting and boiling points,

• discusses the role of energy transfer during changes of state,

• reaches a justified conclusion supported by scientific evidence.

……

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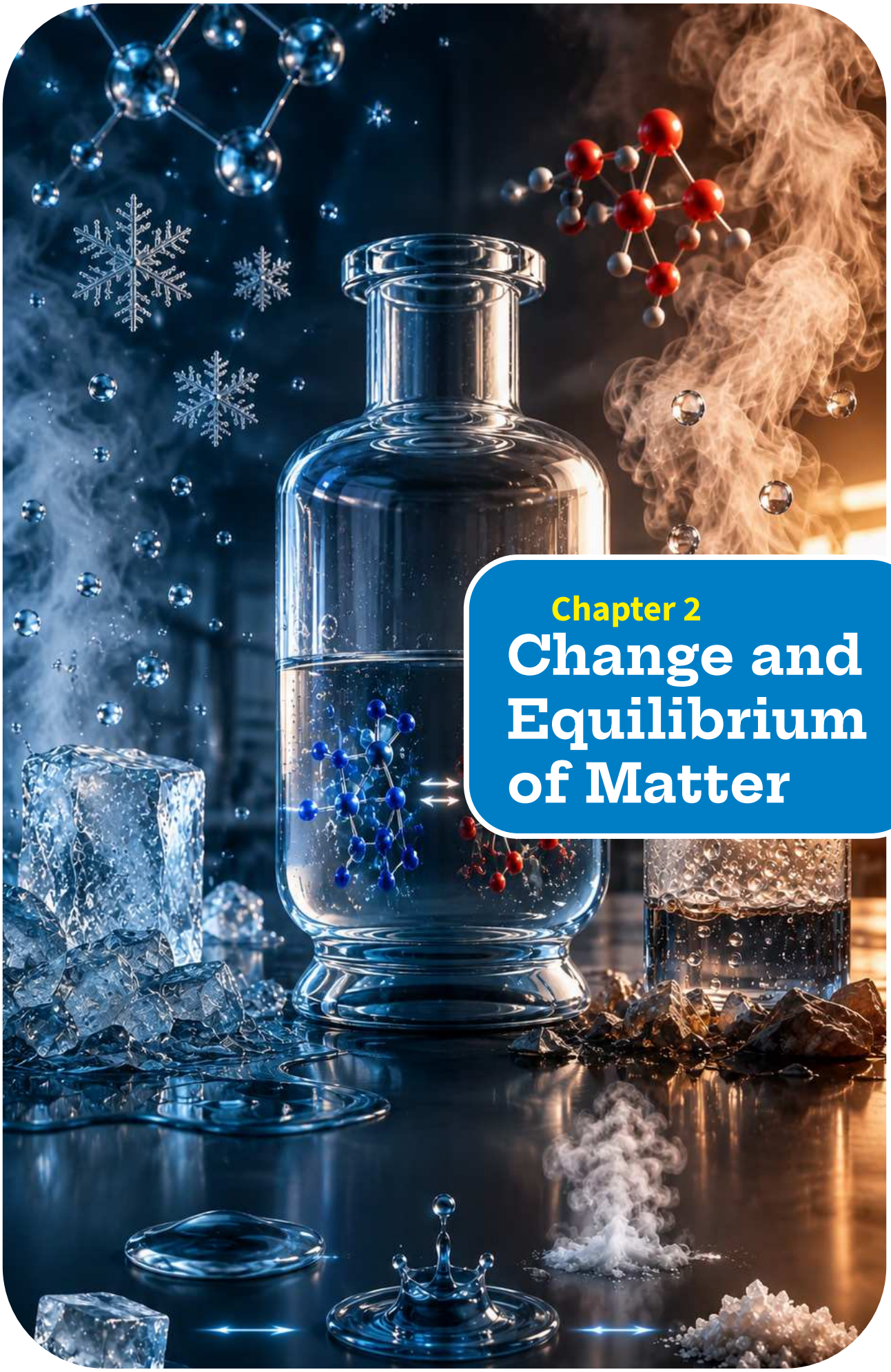

Chapter 2

Change and Equilibrium of Matter

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2-1 — Chemical Reactions and Enthalpy Changes

✨ Engaging Introduction

Imagine holding an instant cold pack after a sports injury. As soon as you squeeze it, it suddenly becomes cold without ever being put in a refrigerator. In another situation, a campfire releases heat and light that keep people warm on a cold night. In this lesson we will explore how chemists track the energy changes during chemical reactions, and how these invisible energy transfers shape the world around us.

❓ **Guiding question:** How can scientists use energy changes in chemical reactions to explain and predict physical and chemical phenomena?

🔭 Exploration

Hot or Cold?

Consider the following situations:

• Burning natural gas in a kitchen stove.

• Dissolving ammonium nitrate in water inside a cold pack.

• Evaporation of sweat from the skin.

Without studying the lesson:

• Which processes release energy? .....

• Which processes absorb energy? .....

Record your initial ideas and revisit them after studying enthalpy changes.

.....

📌 Point!

1. Chemical reactions and enthalpy

(a) Chemical reactions and heat transfer

(i) Exothermic reaction: A reaction that releases heat to the surroundings.

(ii) Endothermic reaction: A reaction that absorbs heat from the surroundings.

(b) **Enthalpy** : A quantity representing the heat content (energy) of a substance.
Denoted by the symbol (H).
The unit is Joules (Symbol: J).

(c) **Enthalpy of reaction** : The change in enthalpy during a chemical reaction.
Denoted by the symbol ΔH.

(d) Sign of enthalpy of reaction

The value of ΔH is **negative** for exothermic reactions and positive for endothermic reactions.

Exothermic reactions release heat
Endothermic reactions absorb heat

structure of science

Key Fact :

Exothermic reactions release heat to the surroundings. - Endothermic reactions absorb heat from the surroundings. - The enthalpy of combustion is always negative.

Key Concepts:

· Chemical reaction
· Heat transfer
· Enthalpy (H)
· Enthalpy change (ΔH)
· Exothermic reaction
· Endothermic reaction
· Enthalpy of combustion
· Enthalpy of formation
· Enthalpy of solution
· Enthalpy of neutralisation.

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Investigating Energy Changes

Students observe two safe demonstrations:

Investigation A

Dissolve calcium chloride in water.

Investigation B

Dissolve ammonium nitrate in water.

Students:

• Measure temperature before and after mixing.

• What is your observations? .....

• Classify each process as exothermic or endothermic. .....

• Infer the direction of energy transfer. .....

Inquiry Question

What evidence allows scientists to conclude that energy has entered or left a system?

.....

2. Expressing the enthalpy of reaction

1. Write the chemical equation.
2. Write the physical state of the substance after the chemical formula.

   Note: If allotropes exist, write the name of substance .

   Example: C (graphite)
3. Make the coefficient of the substance of interest 1 .
4. Write ΔH after the reaction equation .

Example: The reaction where 1 mol of hydrogen H_2 burns to produce water H_2O (Enthalpy of reaction is −286 kJ)

1. $2H_2 + O_2 \longrightarrow 2H_2O$
2. $2H_{2(g)} + O_{2(g)} \longrightarrow 2H_2O_{(l)}$
3. $H_{2(g)} + \frac{1}{2} O_{2(g)} \longrightarrow H_2O_{(l)}$
4. $H_{2(g)} + \frac{1}{2} O_{2(g)} \longrightarrow H_2O_{(l)} \quad \Delta H = -286\ kJ$

Think Critically

A company advertises:

«Our new fuel releases twice as much heat as ordinary fuel, therefore it is always better for the environment.»

Claim–Evidence–Reasoning

Students evaluate:

• Is the claim scientifically valid? .....

• What evidence is missing? .....

• Does higher energy release always mean better sustainability?.....

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3. Types of enthalpy of reaction

(a) Enthalpy change during phase change: When a substance changes state, its enthalpy changes.The enthalpy of phase change is defined as the enthalpy change when 1mol of a substance undergoes a phase transition.

(b) **Enthalpy of combustion:** The enthalpy of reaction when 1mol of a substance undergoes complete combustion. It always takes a negative value. (Because heat is released)

(c) **Enthalpy of solution:** The enthalpy of reaction when 1 mol of a substance dissolves in a large amount of solvent.

- The dissolution of a substance in water is expressed using "aq", which represents a large amount of water.

Example: The enthalpy of solution of sodium hydroxide NaOH is −44.5 kJ/mol.

$$NaOH_{"s"} \longrightarrow NaOH_{"aq"} \quad \Delta H = -44.5\ kJ$$

(d) **Enthalpy of neutralisation:** The enthalpy of reaction when an acid and a base react to form 1 mol of water.

(e) **Enthalpy of formation**: The enthalpy of reaction when 1 mol of a compound is formed from its constituent elements in their standard states.

Types of reaction enthalpy at a glance

Type	Defined per…	Sign
Combustion	1 mol substance fully burned	always negative
Solution	1 mol dissolved in much solvent	±
Neutralisation	1 mol water formed (acid + base)	negative
Formation	1 mol compound from elements	±
Phase change	1 mol undergoing a transition	±

Life Application

Instant Hot and Cold Packs: These rely on specific enthalpy changes. An instant hot pack utilizes an exothermic reaction (like magnesium and water or a combination of iron, carbon, and a salt mixture when the pack is squeezed or crushed), releasing heat to your surroundings. A cold pack utilizes an endothermic reaction (like dissolving ammonium nitrate in water), absorbing heat and cooling your skin.

Be Global Citizen

Understanding enthalpy changes helps scientists:
- Design cleaner fuels.
- Improve battery technologies.
- Develop efficient industrial processes.
- Reduce global energy consumption.

Many modern sustainability initiatives rely on controlling energy transfers in chemical reactions.

Warm Up

Answer the following questions.

(a) Explain what ΔH represents in the following chemical equation.

Identify all substances and types of enthalpy that could be described by this ΔH value.

$$C(graphite) + O_{2(g)} \longrightarrow CO_{2\,(g)}\ \Delta H = -394\ kJ.$$

(b) Express the following chemical changes or phase transitions as thermochemical equations.

(i) When 1 mol of ethane C_2H_6 undergoes complete combustion, 1562 kJ of heat is released.

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(ii) When 9.0 g of water evaporated, it absorbed 22 kJ of heat from the surroundings. (H = 1.0, O = 16).

Explanation

(a) The substance of interest in the chemical equation always has a coefficient of 1.

First, since 1 mol of graphite reacts with oxygen, it can be considered a reaction where graphite undergoes complete combustion. In this case, ΔH represents the enthalpy of combustion of graphite.

Also, it is a reaction where 1 mol of carbon dioxide is formed from carbon (graphite) and oxygen, so in this case, it represents the enthalpy of formation of carbon dioxide.

Based on the above, the value represents the enthalpy of combustion of graphite and the enthalpy of formation of carbon dioxide.

(b) Write according to the procedure.

(i) ❶ Write the chemical equation.

$$2C_2H_6 + 7O_2 \longrightarrow 4CO_2 + 6H_2O$$

❷ Write the physical state of the substance after the chemical formula.

$$2C_2H_{6(g)} + 7O_{2(g)} \longrightarrow 4CO_{2(g)} + 6H_2O_{(l)}$$

❸ Since it represents the reaction of 1 mol of ethane, set the coefficient of C_2H_6 to 1.

$$C_2H_{6(g)} + \frac{7}{2}O_{2(g)} \longrightarrow 2CO_{2(g)} + 3H_2O_{(l)}$$

❹ Write ΔH after the reaction equation.

Noting that the enthalpy of combustion is negative, the enthalpy of combustion of 1 mol of ethane is −1562 kJ. Therefore,

$$C_2H_{6(g)} + \frac{7}{2}O_{2(g)} \longrightarrow 2CO_{2(g)} + 3H_2O_{(l)} \quad \Delta H = -1562 \text{ kJ}$$

(ii) ❶ ❷ Write the reaction equation.

$$H_2O_{(l)} \longrightarrow H_2O_{(g)}$$

❸ ❹ Since the coefficient of H_2O is 1, write ΔH after the reaction equation.

Note here that the enthalpy of reaction is expressed per 1 mol of the substance of interest.

The amount of substance for 9.0 g of water is $\frac{9.0 \text{ g}}{18 \text{ g/mol}} = 0.50$ mol

Therefore, since the heat absorbed when 0.50 mol of water evaporates is 22 kJ, the enthalpy of reaction when 1 mol of water evaporates is 44 kJ.

Thus, $H_2O_{(l)} \longrightarrow H_2O_{(g)} \quad \Delta H = 44$ kJ

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Data Interpretation Activity

Analyze Experimental Data

Substance Dissolved	Initial Temp (°C)	Final Temp (°C)
NaOH	25	34
NH_4NO_3	25	18

Think Like a Chemist

1. Which process is exothermic? .....
2. Which process is endothermic? .....
3. What evidence supports your conclusion?.....
4. Which process has $\Delta H > 0$? .....

Try

Answer on the Following Questions.

1. State the specific type of reaction enthalpy represented by ΔH in the following chemical equation, and specify the substance it refers to.

(a) $HCl_{(aq)} + KOH_{(aq)} \longrightarrow KCl_{(aq)} + H_2O_{(l)} \quad \Delta H = -56\ kJ$

(b) $C_2H_{6(g)} + \frac{7}{2}O_{2(g)} \longrightarrow 2CO_{2(g)} + 3H_2O_{(l)} \quad \Delta H = -1562\ kJ$

2. Express the following changes as thermochemical equations. (H = 1.0, N = 14, O = 16)

(a) When 1 mol of methane CH_4 undergoes complete combustion producing carbon dioxide and water, 891 kJ of heat is released.

(b) When 1 mol of hydrogen H_2 burns to produce gaseous H_2O, 242 kJ of heat is released.

(c) When 1 mol of graphite is exposed to steam to produce carbon monoxide and hydrogen, 131 kJ of heat is absorbed.

(d) When 4.0 g of ammonium nitrate NH_4NO_3 is dissolved in a large amount of water, 1.3 kJ of heat is absorbed.

Answer: _____

3. Express the following phase transitions as thermochemical equations.

(a) The enthalpy of vapourisation of bromine is 31 kJ/mol.

(b) The enthalpy of condensation of ethanol C_2H_5OH is −39 kJ/mol.

Exercise

Choose the correct answer:

1. Why is the enthalpy of combustion always negative?

A. Products contain no energy.

B. Combustion absorbs heat.

C. Heat is released to the surroundings.

D. Oxygen is consumed.

Answer: _____

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2. Which type of enthalpy change occurs when an acid reacts with a base to form water?

A. Enthalpy of formation

B. Enthalpy of combustion

C. Enthalpy of solution

D. Enthalpy of neutralization

Answer: _____

Answer on the following questions

3. State the specific type of reaction enthalpy represented by ΔH in the following chemical equation, and specify the substance it refers to.

(a) $HCl_{(aq)} + NaOH_{(aq)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)}$ $\Delta H = -56$ kJ

(b) $CO_{(g)} + \frac{1}{2}O_{2(g)} \longrightarrow CO_{2(g)}$ $\Delta H = -283$ kJ

Answer: _____

4. Express each change as a thermochemical equation. (H = 1.0, O = 16, Na = 23)

(a) When 1 mol of diamond undergoes complete combustion, 395 kJ of heat is released.

(b) When 4.0 g of solid NaOH is dissolved in a large amount of water, 4.5 kJ of heat is released.

(c) When 1 mol of nitric oxide NO is formed from nitrogen N_2 and oxygen O_2, 90 kJ of heat is absorbed.

Answer: _____

5. Express each phase transition as a thermochemical equation.

(a) The enthalpy of vaporisation of ethanol C_2H_5OH is 39 kJ/mol.

(b) The enthalpy of sublimation of iodine is 62 kJ/mol.

Answer: _____

Challenge Your Thinking

A chemical reaction has:

ΔH=−250 kJ

A student claims:

«The reaction absorbed 250 kJ of energy because the magnitude is large.»

Evaluate the claim.

• Is the reasoning correct? .....

• what sign is meant? .....

• How would the surroundings be affected? .....

• Use scientific evidence to justify your answer. .....

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2-2 — Hess's Law

✨ Engaging Introduction

In chemistry, reactions can follow different pathways — and, surprisingly, the total energy change stays the same regardless of the route. In this lesson we explore how chemists determine unknown energy changes using Hess›s law.

❓ Guiding question: How can scientists determine the energy change of a reaction that cannot be measured directly?

Exploration

Students examine three reactions: A → B · B → C · A → C. Investigate: - Can ΔH(A→C) be predicted from the other two reactions? ..... - What evidence supports your conclusion? .....

📌 Point!

Hess's law

(a) **Hess's law:** The law stating that if the initial and final states of a reaction are determined, the total enthalpy of reaction is constant, regardless of the reaction pathway.

(b) **Calculating the enthalpy of reaction using Hess's law:**

1. Let the required enthalpy of reaction be x [kJ/mol], and write the chemical equation for the target reaction.
2. Write all the chemical equations for the reactions whose enthalpies of reaction are given.
3. Combine the chemical equations written in 2 to form the chemical equation in 1.
4. Calculate the required enthalpy of reaction.

Example: When the enthalpy of combustion of graphite C is −394 kJ/mol and the enthalpy of combustion of carbon monoxide CO is −283 kJ/mol, find the enthalpy of formation of carbon monoxide.

1. Let the required enthalpy of formation be x [kJ/mol], and write the chemical equation representing the formation of carbon monoxide CO.

$$C(\text{graphite}) + \frac{1}{2}O_{2(g)} \longrightarrow CO_{(g)} \quad \Delta H = x\ [kJ]$$

Expressed so that the coefficient of CO becomes 1

2. Write the chemical equations for the combustion of C (graphite) and CO, for which the enthalpies of reaction are given.

$$C(\text{graphite}) + O_{2(g)} \longrightarrow CO_{2(g)} \quad \Delta H = -394\ kJ \ \ldots\ldots(i)$$

$$CO_{(g)} + \frac{1}{2}O_{2(g)} \longrightarrow CO_{2(g)} \quad \Delta H = -283\ kJ \ \ldots\ldots(ii)$$

3. Combine the chemical equations written in 2 to form the chemical equation in 1.
   In the chemical equation of 1,
   The coefficient of C is 1 and it is on the left side of the arrow, so add equation (i) in the same direction.
   The coefficient of CO is 1 and it is on the right side of the arrow, so add equation (ii) in the reverse direction.

$$C(\text{graphite}) + O_2(g) \longrightarrow CO_2(g)$$
$$+)\ CO_2(g) \longrightarrow CO(g) + \frac{1}{2}O_2(g)$$
$$C(\text{graphite}) + \cancel{O_2(g)} + \cancel{CO_2(g)} \longrightarrow \cancel{\frac{1}{2}O_2\ CO_2(g)} + CO(g) + \cancel{\frac{1}{2}O_2(g)}$$
$$\Rightarrow C(\text{graphite}) + \frac{1}{2}O2(g) \longrightarrow CO(g)$$

structure of science

Key Fact :

The total enthalpy change of a reaction is the same regardless of the pathway taken between the reactants and products.

Key Concepts:

- Enthalpy change (ΔH)
- Hess's law
- Enthalpy of formation
- Enthalpy of combustion
- Bond enthalpy
- Thermochemical equations.

Scientific law

Hess's law — the total enthalpy change is independent of the reaction pathway.

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When a reaction is reversed, consider the equation as subtracted.
Therefore, calculating (i) − (ii) yields the chemical equation of ❶.

❹ Calculating the enthalpy of reaction in the same way as the transformation made in ❸

$x = \frac{-394-(-283)}{} = -111$ [kJ]

(Enthalpy of reaction of equation (i)) − (Enthalpy of reaction of equation (ii))

From the above, the enthalpy of formation of CO is −111 kJ/mol

(c) Bond enthalpy: The energy required to break covalent bonds within a molecule. Expressed as a value per 1 mol of bonds in the molecule.

- In a single molecule, if there are multiple bonds between atoms, the bond enthalpy represents the energy required to break all the bonds.

Example: The reaction converting methane CH4 into a carbon atom and hydrogen atoms

$$CH_{4(g)} \longrightarrow C_{(g)} + 4H_{(g)}$$

The bond enthalpy of this reaction is the energy to break 4 C–H bonds.

Key tools

Tool	Rule
Reverse a reaction	change the sign of ΔH (subtract it)
Multiply a reaction ×n	multiply ΔH by n
From bond enthalpies	ΔH = Σ(bonds broken) − Σ(bonds formed)
From formation enthalpies	ΔH = Σ ΔH_f(products) − Σ ΔH_f(reactants)

Warm Up

Answer the following questions.

(a) Calculate the enthalpy of formation [kJ/mol] of propane C_3H_8. Assume that the enthalpies of combustion of graphite, hydrogen, and propane are −394 kJ/mol, −286 kJ/mol, and −2219 kJ/mol, respectively.

(b) Using the following chemical equations, calculate the bond enthalpy [kJ/mol] of the O-H bond, and round your answer to the nearest integer.

$$H_{2(g)} + \frac{1}{2}O_{2(g)} \longrightarrow H_2O_{(g)} \quad \Delta H = -242 \text{ kJ}$$

$$H_{2(g)} \longrightarrow 2H_{(g)} \quad \Delta H = 436 \text{ kJ}$$

$$O_{2(g)} \longrightarrow 2O_{(g)} \quad \Delta H = 498 \text{ kJ}$$

Explanation

(a) ❶ Write the chemical equation representing the formation of propane C_3H_8. Let x [kJ/mol] represent the enthalpy of formation of propane.

$$3C(\text{graphite}) + 4H_{2(g)} \longrightarrow C_3H_{8(g)} \quad \Delta H = x \text{ [kJ]}$$

❷ Write the chemical equations and enthalpy changes for the combustion reactions of the substances whose enthalpy values are given. Since the enthalpy of combustion of graphite is −394 kJ/mol,

$$C(\text{graphite}) + O_{2(g)} \longrightarrow CO_{2(g)} \quad \Delta H = -394 \text{ kJ} \quad \ldots\ldots(i)$$

NOS: Philosophy of Science

Hess's Law demonstrates:

- Objectivity: Different scientists obtain the same ΔH when using the same data.
- Cumulativity: Hess law was built on earlier work concerning energy conservation to develop a more powerful method for calculating reaction enthalpies.

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Since the enthalpy of combustion of hydrogen is −286 kJ/mol,

$H_{2(g)} + \frac{1}{2}O_{2(g)} \longrightarrow H_2O_{(l)}$ $\Delta H = -286$ kJ .....(ii)

Since the enthalpy of combustion of propane is −2219 kJ/mol,

$C_3H_{8(g)} + 5O_{2(g)} \longrightarrow 3CO_{2(g)} + 4H_2O(l)$ $\Delta H = -2219$ kJ .....(iii)

❸ Combine the equations written in ❷ to form the chemical equation in ❶.

This can be derived using the relationship: (i)×3+(ii)×4−(iii).

❹ Calculating the enthalpy of reaction in the same way as formed in ❸,

$x = \{-394 \times 3 + (-286) \times 4\} - (-2219)$

$= -107$

Therefore, the required enthalpy of formation is −107 kJ/mol

(b) ❶ Let x [kJ/mol] represent the bond enthalpy.

$H_2O_{(g)} \longrightarrow 2H_{(g)} + O_{(g)}$ $\Delta H = x$ [kJ]

❷ Write the chemical equations and their corresponding enthalpy changes:

$H_{2(g)} + \frac{1}{2}O_{2(g)} \longrightarrow H_2O_{(g)}$ $\Delta H = -242$ kJ .....(i)

$H_{2(g)} \longrightarrow 2H_{(g)}$ $\Delta H = 436$ kJ .....(ii)

$O_{2(g)} \longrightarrow 2O_{(g)}$ $\Delta H = 498$ kJ .....(iii)

❸ The equation in ❶ can be obtained by: (ii)+(iii)×$\frac{1}{2}$−(i).

❹ Calculating using the same combination from ❸: gives 436 kJ+249 kJ+242 kJ = 927 kJ

Since H_2O contains 2 O−H bonds, the bond enthalpy is: 927 kJ × $\frac{1}{2}$ = 463.5 kJ ≈ 464 kJ 464 kJ/mol.

Challenge your thinking

Many industrial reactions occur at temperatures and pressures that make direct enthalpy measurements difficult.

How can Hess's Law help in estimating energy changes before building a large-scale chemical plant?

.....

Try

. Given the following enthalpies of formation:

- $CO_{2(g)}$: −394 kJ/mol
- $H_2O_{(g)}$: −286 kJ/mol
- $C_2H_5OH_{(l)}$: −277 kJ/mol.

(**a**) Write the chemical equation representing the combustion of ethanol, including the physical states.

Answer: _____

(**b**) Calculate the enthalpy of combustion of ethanol to the nearest integer.

Answer: _____

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Exercise

Choose the correct answer:

1. Which scientific principle forms the basis of Hess›s law?

A. Conservation of mass
B. Conservation of energy
C. Le Chatelier›s principle
D. Boyle›s law

Answer: _____

2. Which statement best describes Hess›s law?

A. Enthalpy depends on reaction rate
B. Enthalpy depends on catalyst type
C. The total enthalpy change depends only on the initial and final states
D. Enthalpy depends on the reaction pathway.

Answer: _____

Answer on the following questions

3. Write the equation for the combustion of ethane $C_2H_{6(g)}$ including its enthalpy change, using the following data:

$C(graphite) + O_{2(g)} \longrightarrow CO_{2(g)} \quad \Delta H = -394\ kJ \quad ...(i)$

$H_{2(g)} + \frac{1}{2} O_{2(g)} \longrightarrow H_2O_{(l)} \quad \Delta H = -286\ kJ \quad ...(ii)$

$2C(graphite) + 3H_{2(g)} \longrightarrow C_2H_{6(g)} \quad \Delta H = -84\ kJ \quad ...(iii)$

Answer: _____

4. Calculate ΔH for the following reaction.

$2H_{2(g)} + O_{2(g)} \longrightarrow 2H_2O_{(g)}$

Given:

- Bond enthalpy of H−H: 436 kJ/mol
- Bond enthalpy of O=O: 498 kJ/mol
- Bond enthalpy of O−H: 463 kJ/mol

Challenge Your Thinking

$C(graphite) + O_{2(g)} \rightarrow CO_{2(g)} \quad \Delta H = -394\ kJ$

$H_{2(g)} + \frac{1}{2} O_{2(g)} \rightarrow H_2O_{(l)} \quad \Delta H = -286\ kJ$

$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(l)} \quad \Delta H = -891\ kJ$

Determine the enthalpy of formation of methane:

$C(graphite) + 2H_{2(g)} \rightarrow CH_{4(g)}$

Explain every step using Hess's Law.

_____

_____

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2-3 — Electrochemical Cell (1) (Daniell Cell)

✨ Engaging Introduction

Imagine that a power outage suddenly occurs in your city. Within seconds, millions of people depend on batteries, generators, and backup power systems to keep hospitals, communication networks, and transportation operating. But where does this electrical energy come from?

Surprisingly, electricity can be produced through simple chemical reactions involving metals and ions. Every battery, from a smartphone battery to an electric vehicle, relies on the same fundamental principle.

In this lesson, we will explore how chemical reactions can be transformed into electrical energy and how electrochemical cells power modern technology.

❓ **Guiding question:** How can a spontaneous chemical reaction be used to generate electrical energy that powers the devices and technologies we use every day?

🔬 Exploration

Materials

- Lemon, potato, or orange
- Galvanized nail (zinc-coated)
- Small LED
- Copper coin or copper strip
- Connecting wires

Procedure

1. Insert the zinc nail and copper strip into the fruit.
2. Connect wires to both metals.
3. Observe whether electrical energy is produced.
4. Test different fruits and compare performance.

structure of science

Key Fact :

An electrochemical cell converts chemical energy into electrical energy through a spontaneous redox reaction in which oxidation occurs at the anode and reduction occurs at the cathode.

Key Concepts:

· Electrochemical cell

· Anode

· Cathode

· Electromotive force (EMF)

· Daniell cell.

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Inquiry Questions

• Which fruit produces the greatest voltage?

.....

• Does changing the electrode metals affect performance?

.....

• What evidence indicates that a redox reaction is occurring?

.....

Point!

1. Electrochemical cell

(a) Electrochemical cell: A device that converts chemical energy into electrical energy using an oxidation-reduction (redox) reaction.

• The electrode from which electrons (e−) are released is called the anode (−), and the electrode that receives them is called the cathode (+).

(b) Reactivity series of metals: The arrangement of metals in order of their reactivity (or tendency to undergo oxidation).

$Li > K > Ca > Na > Mg > Al > Zn > Fe > Ni > Sn > Pb > (H_2) > Cu > Hg > Ag > Pt > Au$

(c) Electromotive force (EMF) : The voltage (potential difference) generated between the cathode and anode. The greater the difference in the reactivity series between the two metals used in the cell, the greater the EMF.

(d) Electrochemical Cell Notation

Represented in the form "(−) anode | Aqueous electrolyte solution | cathode (+)". This is called the cell notation .

Figure 2.3.1 metal samples

2. Daniell cell

Daniell cell : A galvanic cell consisting of a zinc plate immersed in an aqueous zinc sulfate ($ZnSO_4$) solution and a copper plate immersed in an aqueous copper(II) sulfate ($CuSO_4$) solution. The two half-cells are separated by a porous pot and connected by a conducting wire. (Figure on the right)

(a) Cell notation: (−) Zn | $ZnSO_{4(aq)}$ | $CuSO_{4(aq)}$ | Cu (+)

(b) Reactions at electrodes

• Reaction at the anode: $Zn \longrightarrow Zn^{2+} + 2e^-$

• Reaction at the cathode: $Cu^{2+} + 2e^- \longrightarrow Cu$

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(c) Characteristics

- During discharge, Zn^{2+} from the aqueous zinc sulfate solution side and SO_4^{2-} from the aqueous copper(II) sulfate solution side move through the porous pot to the opposite aqueous solutions.

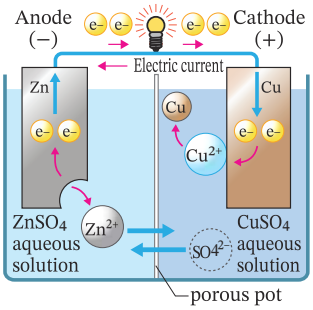


Figure 2.3.2 Daniell cell

Quick reference

Electrode	Sign	Process
Anode	−	oxidation — releases electrons ($Zn \rightarrow Zn^{2+} + 2e^-$)
Cathode	+	reduction — receives electrons ($Cu^{2+} + 2e^- \rightarrow Cu$)

Life Application

Every battery in a smartphone, laptop, smartwatch, or electric vehicle operates using electrochemical principles similar to those found in the Daniell cell.

Understanding electrochemical cells helps scientists develop:

- Longer-lasting batteries
- Faster charging systems
- More sustainable energy storage technologies

Be Global Citizen

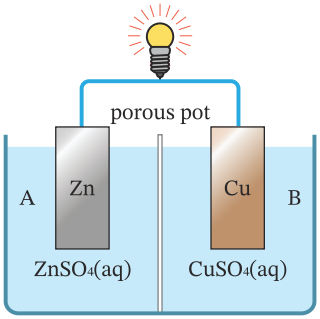
Electrochemical cells play a major role in sustainable development. Where it uses in Electric vehicles, Renewable energy storage, Portable medical devices, Emergency power systems, Satellite technologies

Advances in battery technology can reduce fossil fuel dependence and support global sustainability goals.

Warm Up

The figure is a schematic of a Daniell cell. Answer the following.

The figure on the right is a schematic diagram of a Daniell cell. Answer the following questions.



(**a**) Express the reactions occurring at the cathode (+) and anode (−) respectively,

using ionic equations containing electrons (e−).

(**b**) To maximise the discharge time, what should the initial concentrations of aqueous solutions A and B be? Answer using the terms 'high concentration' and 'low concentration'.

Explain your reasoning by focusing on the 'increase or decrease of ions' at each electrode.

Explanation

(a) Cathode (+): $Cu^{2+} + 2e^- \rightarrow Cu$. Anode (−): $Zn \rightarrow Zn^{2+} + 2e^-$.

(b) [Concentration Condition]

The concentration of aqueous solution A ($ZnSO_4$) is set to be low, and the concentration of aqueous solution B ($CuSO_4$) is set to be high.

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[Reason]

At the anode, Zn^{2+} ions are produced as the reaction proceeds. By starting with a low concentration of $ZnSO_4$ solution, it takes longer for the solution to reach saturation, allowing more zinc to dissolve. In contrast, at the cathode, Cu^{2+} ions are consumed. By using a high concentration of $CuSO_4$ solution initially, the depletion of Cu^{2+} ions is delayed, ensuring the reaction continues for a longer period.

!? Problem-Solving

Analyze Experimental Data

Two electrochemical cells are constructed:

Cell A: Zn | Cu

Cell B: Mg | Cu

Using the reactivity series:

- Predict which cell produces the higher EMF. .....
- Explain your reasoning. .....
- Identify the anode and cathode in each cell. .....

Try

Answer the following about the cell shown:

(a) What is the name of the cell shown in the figure on the right?

(b) Which metal plate is the cathode (+)? Answer with its chemical symbol.

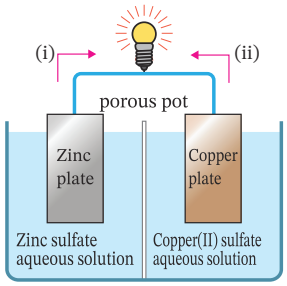
(c) When the zinc plate and the copper plate are connected by a conducting wire, express the changes that occur at both electrodes using ionic equations containing electrons (e^-).

(d) Which direction, (i) or (ii) in the figure, do the electrons flow in the conducting wire?

(e) To maximize the total electrical charge delivered, how should the initial concentrations of the aqueous zinc sulfate solution and the aqueous copper(II) sulfate solution be chosen?

(f) In this cell, a potential difference is generated between the two electrodes. What is this potential difference called?

(g) If the zinc plate is replaced with a nickel plate and the aqueous solution is replaced with an aqueous nickel(II) sulfate solution, how will the potential difference change compared to that in (f)?



Answer: _____

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Exercise

Choose the correct answer:

1. Which electrode gains mass during the operation of a Daniell cell?

A. Zinc electrode

B. Copper electrode

C. Both electrodes

D. Neither electrode

Answer: _____

2. In a Daniell cell, oxidation occurs at the:

A. Cathode

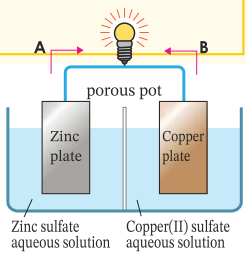
B. Electrolyte

C. Anode

D. Porous pot

Answer: _____

3. Answer the following questions about the cell shown in the figure on the right.



(a) Express the changes occurring at the anode (−) and cathode (+) respectively during discharge using reaction equations with electrons (e−).

(b) Which is the direction of the electric current, A or B in the figure?

(c) Which of the following moves from the aqueous copper(II) sulfate solution to the aqueous zinc sulfate solution through the porous pot? Answer with the corresponding number.

(i) Zn (ii) Zn^{2+} (iii) Cu (iv) Cu^{2+} (v) H^{+} (vi) SO_4^{2-}

Challenge your thinking

A Daniell cell uses:

- Zn electrode in $ZnSO_4$ solution
- Cu electrode in $CuSO_4$ solution

A student proposes increasing the concentration of $ZnSO_4$ and decreasing the concentration of $CuSO_4$ to make the cell last longer.

Evaluate this proposal.

- Will it increase or decrease discharge time? .....
- Explain using changes in Zn^{2+} and Cu^{2+} concentrations at both electrodes.

.....

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2-4 — Electrochemical Cell (2) (Various Cells)

✨ Engaging Introduction

A hydrogen-powered bus travels through a city without producing smoke, carbon dioxide, or harmful pollutants. Instead, the only substance released from its exhaust is water.At the same time, millions of cars around the world rely on lead-acid batteries to start their engines every day.

In this lesson, we will explore how different electrochemical cells store and produce electricity, and how scientists use chemical evidence to explain and predict their performance.

❓ **Guiding question:** How can chemical reactions be designed and controlled to provide electrical energy for different real-world applications?

Point!

1. Various cells

(a) Lead–acid battery: A battery using lead Pb for the anode, lead(IV) oxide PbO_2 for the cathode, and dilute sulfuric acid as the electrolyte.

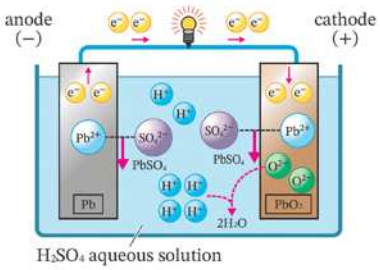

Figure 2.4.1 Lead–acid battery

(i) Cell notation: (−)Pb | H_2SO_4(aq) | PbO_2(+)

(ii) Reactions at electrodes (during discharge)

- Reaction at the anode: $Pb + SO_4^{2-} \longrightarrow PbSO_4 + 2e^-$
- Reaction at the cathode: $PbO_2 + 4H^+ + SO_4^{2-} + 2e^- \longrightarrow PbSO_4 + 2H_2O$
- Overall reaction: $Pb + PbO_2 + 2H_2SO_4 \longrightarrow 2PbSO_4 + 2H_2O$

(iii) Characteristics

Because H_2SO_4 is used and H_2O is produced

- The concentration of sulfuric acid becomes lower due to discharge.
- An external power source is connected to the lead-acid battery to charge it. During charging, reverse electrode reactions (opposite to discharge) occur at both the anode and cathode.

(b) Fuel cell : A device that extracts electrical energy using fuel (reducing agent) such as hydrogen, and an oxidant such as oxygen.

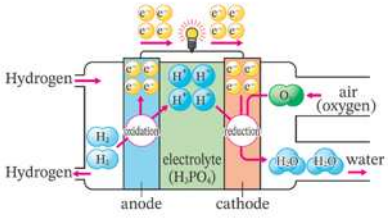

Figure 2.4.2 Fuel cell

(i) Cell notation (phosphoric acid type):

(−) H_2 | H_3PO_4(aq) | O_2 (+)

(ii) Reactions at electrodes (phosphoric acid type)

- Reaction at the anode: $H_2 \longrightarrow 2H^+ + 2e^-$
- Reaction at the cathode: $O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$
- Overall reaction: $2H_2 + O_2 \longrightarrow 2H_2O$

structure of science

Key Fact :

Electrochemical cells convert chemical energy into electrical energy through redox reactions, and the quantity of electricity produced depends on the amount of electrons transferred.

Key Concepts:

- Electrochemical cell
- Lead-acid battery
- Fuel cell
- Oxidation
- Reduction
- Faraday constant
- Electric charge
- Electrolyte
- Electrode reactions.

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Think as an Engineer

Engineers designing electric vehicles must decide whether to use:

• Lead-acid batteries

• Lithium-ion batteries

• Hydrogen fuel cells

Challenge

Which technology would you choose for:

A school bus?.....

A passenger car. .....

A backup power system? .....

Justify your choice using scientific evidence.....

2. Quantity of electricity

(a) Expressing the quantity of electricity

The quantity of electricity when a current of 1 Ampere flows for (1 second) is expressed in a unit called 1 C (Coulomb).

(b) Faraday constant: The magnitude of the quantity of electricity per 1 mol of electrons. Denoted by the symbol F.

$$F = 9.65\times10^{4}\ C/mol$$

• The quantity of electricity that flow can be found using the Faraday constant.

Total electric charge [C] = Faraday constant [C/mol] × Amount of substance of electrons [mol]

(c) Chemical equations of cells

In a cell, since the reactions occurring at each electrode are different, consider the reaction equation to use according to what you want to find.

Key reactions & charge

Cell	Anode (−, oxidation)	Cathode (+, reduction)
Lead-acid	$Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$	$PbO_2 + 4H^+ + SO_4^{2-} + 2e^- \rightarrow PbSO_4 + 2H_2O$
Fuel cell (H_3PO_4)	$H_2 \rightarrow 2H^+ + 2e^-$	$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

Life Application

Automobile Batteries

Lead-acid batteries provide the large burst of electrical energy needed to start vehicle engines.

Hydrogen-Powered Vehicles

Fuel cells generate electricity while producing only water as a by-product.

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Warm Up

Answer the following. Assume F = 9.65 × 10^4 C/mol. (H = 1.0, O = 16, S = 32)

(a) Read the following text and answer the questions below. Assume the Faraday constant F = 9.65×10^4 C/mol.

(H = 1.0, O = 16, S = 32)

A lead-acid battery consists of (A) and lead immersed as electrode plates in dilute sulfuric acid. When 1.0 mol of lead completely changes during discharge, a quantity of electricity of (B) C can be extracted, and the dilute sulfuric acid decreases by (C) g.

Also, when charging the lead-acid battery, connect the lead to the (D) pole of the external power source. Upon charging, the mass of both electrode plates (E).

(i) Fill in the blanks ( ) with appropriate words and numerical values. Round to two significant figures.

(ii) Express the changes occurring during charging of the lead-acid battery together as a chemical equation.

(b) Read the following text and answer the questions below.

A fuel cell is a device that extracts the energy of a combustion reaction as electrical energy using fuel and oxygen. In a fuel cell with an aqueous phosphoric acid solution as the electrolyte, hydrogen is (A) at the (B) to become (C), which moves through the electrolyte and reacts with oxygen at the (D) to become (E).

(i) Fill in the blanks ( ) with the appropriate words.

(ii) Express the reactions at the anode and cathode using ionic equations with electrons e−.

Explanation

(a) (i) **A:** lead(IV) oxide

B: Since the amount of change in lead is known and the quantity of electricity is to be found, consider the reaction at the anode.

From the reaction at the anode, $Pb + SO_4^{2-} \longrightarrow PbSO_4 + 2e^-$, when 1.0 mol of lead changes, 2.0 mol of electrons flow.

Since Quantity of electricity flowed [C] = Faraday constant [C/mol]×Amount of substance of electrons [mol], 2.0 mol×9.65×10^4 C/mol = 1.93×10^5 C

≈ 1.9×10^5 C

C: Since considering the amount of decrease in dilute sulfuric acid, consider the overall reaction.

$Pb + PbO_2 + 2H_2SO_4 \longrightarrow 2PbSO_4 + 2H_2O$

When 1.0 mol of lead changes, sulfuric acid decreases by 2.0 mol and water increases by 2.0 mol.

From H_2SO_4 = 98 and H_2O = 18, the amount of decrease in dilute sulfuric acid is,

(98−18) g/mol×2.0 mol = 160 = 1.6×10^2 g

D: Connect the anode and cathode of the lead-acid battery to the negative and positive terminals of the external power supply, respectively.

During charging, the negative terminal of the lead-acid battery (where lead is located)

Misconception Alert

Misconception
„Electricity is stored inside the wires."
Scientific Explanation
Electrical energy is generated by electron transfer during redox reactions.
The wires simply provide a pathway for electron flow.

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is connected to the negative terminal of the external power supply, acting as the cathode. negative.

E: During discharge, Pb and PbO_2 are converted to $PbSO_4$, increasing the electrode mass. During charging, the

reverse reactions occur, decreasing the electrode mass. decreases

(ii) During charging, the reaction in the reverse direction to discharge occurs.

Therefore, $2PbSO_4 + 2H_2O \longrightarrow Pb + PbO_2 + 2H_2SO_4$

(b) (i) **A**: oxidised **B**: anode **C**: hydrogen ions **D**: cathode E: water

(ii) Anode: $H_2 \longrightarrow 2H^+ + 2e^-$

Cathode: $O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$

Identifying variables

A scientist wants to investigate how the amount of electrical charge produced by a lead-acid battery depends on the amount of lead that reacts during discharge. Several identical lead-acid batteries are prepared. The scientist changes the amount of lead available in each battery while keeping all other conditions the same. The total electrical charge produced is then measured.

1. What is the independent variable? .....

2. What is the dependent variable? .....

3. Which variables should be controlled to ensure a fair test? .....

Try

Choose the correct answer:

1. What happens to the sulfuric-acid concentration during discharge of a lead-acid battery?

A. Increases B. Remains constant

C. Decreases D. Doubles

Answer: _____

2. Which substance is produced at the cathode of a hydrogen fuel cell?

A. Hydrogen gas B. Sulfuric acid

C. Water D. Oxygen gas

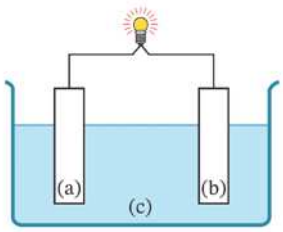
Answer: _____

3. Answer the following questions regarding the lead-acid battery.

Assume the Faraday constant $F = 9.65\times10^4$ C/mol.
(H = 1.0, O = 16, S = 32, Pb = 207)

(a) What substances are used for the (a) anode (−), (b) cathode (+), and (c) electrolyte? Answer each with its chemical formula.

(b) Express the reactions at the anode (−) and cathode (+) during discharge using ionic equations including e−,



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respectively.

(c) Express the overall reaction of the battery during discharge as a chemical equation.

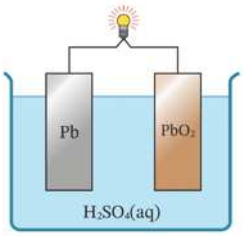
(d) How does the concentration of the electrolyte change due to discharge?

(e) After discharging this battery for a certain period, it was charged, and the mass of the anode decreased by 7.2 g compared to before charging. What is the quantity of electricity in C that flowed during charging? Give your answer to two significant figures.

Exercise

1. The figure below is a schematic diagram of a lead-acid battery. Answer the following questions.

(H = 1.0, O = 16, S = 32, Pb = 207)



(a) Name the substance used for the cathode (+).

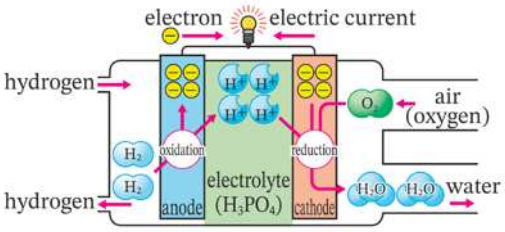
(b) Express the reactions at the cathode (+) and anode (−) during discharge using ionic equations including electrons e−, respectively.

(c) Express the overall reaction of the battery during discharge as a chemical equation.

(d) How does the concentration of the electrolyte change due to discharge?

(e) When a quantity of electricity equivalent to 1.0 mol of electrons flows, by how many grams does the mass of the positive electrode increase or decrease? Give your answer to two significant figures.

2. The figure on the right is a schematic diagram of a fuel cell (phosphoric acid type). A fuel cell extracts the energy generated when hydrogen (fuel) and oxygen react as electrical energy. Answer the following questions.



(a) Regarding the fuel cell (phosphoric acid type), answer the (a) reaction at the cathode (+), (b) reaction at the anode (−), and (c) overall reaction. For (a) and (b), answer with ionic equations including electrons e−, and for (c), answer with a reaction equation.

(b) Calculate the quantity of electricity that flows when 5.6 L of hydrogen is consumed at 0 °C and 1.013×10^5 Pa. Assume sufficient oxygen is present. (Faraday constant: $F = 9.65\times10^4$ C/mol) Express your answer to two significant figures.

Challenge Your Thinking

A lead-acid battery discharges completely and causes 3.0 mol of electrons to flow.

Using:

$F=9.65\times10^4$C/ mol

Calculate:

1. Total charge produced.....

2. Whether the charge would be greater or smaller if 5.0 mol of electrons flowed.

.....

3. Explain your reasoning. .....

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2-5 — Electrolysis (1) (Reactions at Electrodes)

✨ Engaging Introduction

A company wants to produce hydrogen fuel for clean energy and chlorine for water treatment. Instead of adding chemicals, engineers simply pass an electric current through a salt solution. A few minutes later, bubbles appear at both electrodes, and entirely new substances are formed.

Let`s explore in this lesson, How can electricity transform substances into new products?.

❓ Guiding question: How can electrical energy force chemical reactions to occur, and how do chemists predict which substances will be produced at each electrode?

structure of science

Key Fact :

The products of electrolysis depend on both the ions present in solution and the type of electrode used.

Key Concepts:

- Electrolysis
- Reactions at electrodes
- Cation exchange membrane
- Ion exchange membrane method.

📌 **Point!**

1. Electrolysis

(a) Electrolysis: A process that uses electrical energy to drive non-spontaneous redox reactions.

• The reaction at the electrode changes depending on the type of electrode and the type of ions in the aqueous solution.

(b) Reactions at electrodes

《**Reactions at the anode**》

(i) When the electrode is platinum or carbon

• When halide ions (such as Cl^- and I^-) are present

Halide ions are oxidised to form elements . Example: $2I^- \longrightarrow I_2 + 2e^-$

• When other ions (such as sulfate ions SO_4^{2-} and nitrate ions NO_3^-) are included

... When the aqueous solution is acidic or neutral, water H_2O is oxidised to generate O_2.

$2H_2O \longrightarrow O_2 + 4H^+ + 4e^-$

... When the aqueous solution is basic, hydroxide ions OH− are oxidised to generate O_2.

$4OH^- \longrightarrow O_2 + 2H_2O + 4e^-$

(ii) When the electrode is other than platinum or carbon

The metal of the electrode is oxidised and dissolves as cations.

Example: $Cu \longrightarrow Cu^{2+} + 2e^-$

《Reactions at the cathode》 ..... The type of electrode does not matter.

(i) When metal ions with low reactivity (such as Cu^{2+} and Ag^+) are present at the cathode, they are reduced and the corresponding metals are deposited.

Example: $Ag^+ + e^- \longrightarrow Ag$

(ii) When metal ions with a higher reactivity than hydrogen are present, water is preferentially reduced at the cathode rather than the metal ions, generating hydrogen gas.

$2H_2O + 2e^- \longrightarrow H_2 + 2OH^-$

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(iii) When the aqueous solution is acidic, hydrogen ions (H+) are reduced at the cathode to produce hydrogen gas.

$2H^+ + 2e^- \longrightarrow H_2$

The electrodes are platinum, sulfate ions ($SO4^{2-}$) are present, and the aqueous solution is acidic.

(c) Example of electrolysis

〈Electrolysis of aqueous sulfuric acid (H_2SO_4) solution (dilute sulfuric acid (Electrode: Platinum))〉 ●

(i) Anode: $2H_2O \longrightarrow O_2 + 4H^+ + 4e^-$

(ii) Cathode: $2H^+ + 2e^- \longrightarrow H_2$

Inquiry Exploration

Cell	Electrolyte	Electrode
A	NaCl(aq)	Carbon
B	$AgNO_3$(aq)	Silver
C	NaOH(aq)	Platinum

1. Which ions are present in each solution? .....

2. Which ions are most likely to gain electrons? .....

3. Which particles are most likely to lose electrons? .....

2. Ion exchange membrane method

(a) Cation exchange membrane: A membrane through which only cations can pass.

(b) Ion exchange membrane method: A manufacturing method for sodium hydroxide using a cation exchange membrane.

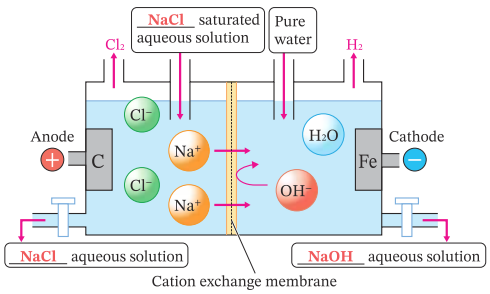
❶ Electrolyze an aqueous sodium chloride solution using carbon and iron electrodes.

- Reaction at the anode: $2Cl^- \longrightarrow Cl_2 + 2e^-$
- Reaction at the cathode: $2H_2O + 2e^- \longrightarrow H_2 + 2OH^-$

Cl_2 is generated on the anode side, and H_2 is generated on the cathode side.

❷ Passing through the cation exchange membrane, Na+ moves to the cathode side.

❸ On the cathode side, the concentrations of OH− and Na+ increase.
→ High-purity sodium hydroxide is obtained by concentrating the solution from the cathode compartment.



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Life Application

The Hydrogen Economy: Society currently depends on fossil fuels (coal, oil, gas), but burning them releases CO_2, driving the greenhouse effect and rising sea levels. Hydrogen (H_2) is an ideal alternative because its combustion produces only water, making it a non-polluting, renewable fuel. The "hydrogen economy" rests on two electrochemical technologies: (i) electrolysis of water — using solar energy to split water into hydrogen; (ii) fuel cells — converting the chemical energy of hydrogen back into electricity. Mastering electrochemistry is a key to a sustainable, carbon-free future.

Warm Up

The solutions (a)–(c) were electrolysed. Write the half-reactions at each electrode.

	(a)	(b)	(c)
Electrolyte	copper(II) chloride solution	silver nitrate solution	sodium hydroxide solution
Anode	C	Ag	Pt
Cathode	C	Ag	Pt

Explanation

(a) Anode: The electrode is carbon, and copper(II) chloride ionizes, providing chloride ions (Cl^-) in the solution. These chloride ions are then oxidised to form elemental chlorine. Therefore, $2Cl^- \longrightarrow Cl_2 + 2e^-$

Cathode: Copper(II) chloride ionizes, and ions of less reactive metals, Cu^{2+}, are present. At this time, the metal ions are reduced and metal is deposited.

Therefore, $Cu^{2+} + 2e^- \longrightarrow Cu$

(b) Anode: Since the electrode is silver, the metal of the electrode is oxidised and dissolves as cations.

Therefore, $Ag \longrightarrow Ag^+ + e^-$

Cathode: Silver nitrate ionizes, and less reactive metal ions, Ag+, are present.

Therefore, $Ag^+ + e^- \longrightarrow Ag$

(c) Anode: The electrode is platinum, and the aqueous sodium hydroxide (NaOH) solution is basic. At this time, hydroxide ions OH− are oxidised.

Therefore, $4OH^- \longrightarrow O_2 + 2H_2O + 4e^-$

Cathode: Sodium hydroxide ionizes, and ions of metals more reactive than hydrogen, Na+, are present. At this time,

water H_2O is reduced to generate H_2.

Therefore, $2H_2O + 2e^- \longrightarrow H_2 + 2OH^-$

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Think Like a Chemist

A student says: "Sodium metal should form during the electrolysis of sodium chloride solution because sodium ions are present".

Evaluate this statement.

• Is sodium more reactive than hydrogen?

.....

• Which species is easier to reduce?

.....

• What evidence supports your conclusion?

.....

Try

Solve the Following Questions

1. The aqueous electrolyte solutions in the table were electrolyzed. Express the changes A to F occurring at each electrode using half-reaction equations.

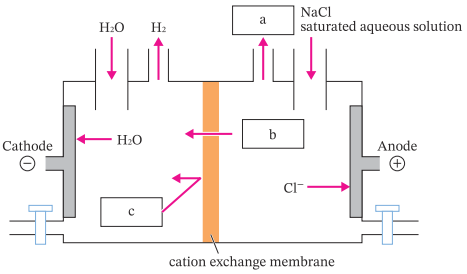
Aqueous electrolyte	Cathode	Change	Anode	Change
(a) Dilute sulfuric acid	Cu	(A)	Cu	(B)
(b) Sodium hydroxide solution	Pt	(C)	Pt	(D)
(c) Copper(II) sulfate solution	Pt	(E)	Pt	(F)

Answer: _____

2. The figure below schematically shows the industrial production of sodium hydroxide by the ion exchange membrane method.

Choose the most appropriate combination of chemical formulas to insert into a to c in the figure from (i) to (vi) below.

	a	b	c
(i)	O_2	Na^+	OH^-
(ii)	O_2	OH^-	OH^-
(iii)	O_2	Na^+	Cl^-
(iv)	Cl_2	OH^-	Cl^-
(v)	Cl_2	Na^+	Cl^-
(vi)	Cl_2	Na^+	OH^-



Answer: _____

Exercise

Choose the correct answer:

1. During electrolysis of $AgNO_3(aq)$, silver metal deposits at the cathode because:

A. Ag^+ ions are easily reduced

B. Water is oxidized

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C. Nitrate ions gain electrons

D. Silver is highly reactive

Answer: _____

2. Which factor would most likely change the products formed during electrolysis?

A. Colour of the container

B. Electrode material

C. Shape of the beaker

D. Position of the power supply

Answer: _____

Answer on the Following Questions

3. When electrolysis is performed using the combinations of electrolyte and electrode from (a) to (d) in the table, express the reactions occurring at the anode and cathode using half-reaction equations, respectively.

	(a)	(b)	(c)	(d)
Electrolyte	Dilute sulfuric acid	KOH solution	$CuSO_4$ solution	NaCl solution
Anode	Pt	Pt	Cu	C (graphite)
Cathode	Pt	Pt	Fe	Fe

Answer: _____

Challenge Your Thinking

A concentrated aqueous solution of sodium chloride is electrolyzed using carbon electrodes.

1. Identify all ions present. .....
2. Predict the product at the anode. .....
3. Predict the product at the cathode. .....
4. Explain why sodium metal is not produced. .....
5. Predict how the pH of the cathode compartment changes .....

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2-6 — Electrolysis (2) (Quantity of Electricity, Two Electrolytic Cells)

✨ Engaging Introduction

A company uses electrolysis to produce pure copper for electrical wires. Engineers know exactly how much copper will be deposited before the process even begins—not by weighing the copper, but by measuring the electric current flowing through the circuit.

In this lesson, we will explore the relationship between electricity, electrons, and chemical change, and discover how chemists use quantitative evidence to predict industrial production.

❓ **Guiding question:** How can chemists predict the amount of substance produced during electrolysis using only electrical measurements such as current and time?

🔬 Exploration

Students can electroplate a coin or a metal key using copper sulfate solution.

Observation

Before electrolysis:

.....

After electrolysis:

.....

Inference

.....

📌 Point!

1. Electrolysis and quantity of electricity

(a) Calculating the Quantity of Electricity Quantity of electricity (C) = Current (A)×Time (s)

(b) Faraday constant F: The magnitude of the quantity of electricity per 1 mol of electrons. 9.65×10^4 C/mol.

(c) the mass of a substance (m) deposited or liberated at an electrode is directly proportional to the quantity of electricity (Q) passed through the electrolyte.

- Expression: $m \alpha Q$
- Since Q=I×t (Current × Time), we can write: m=ZIt
- m = mass of substance deposited (in grams)
- Q = quantity of electricity passed (in Coulombs)
- I = current (in Amperes)
- t = time (in seconds)
- Z = Electrochemical Equivalent of the substance.

Structure of Science

Key Fact :

The amount of substance produced during electrolysis is directly proportional to the quantity of electricity that passes through the circuit.

Key Concepts:

· Electrolysis
· Quantity of electricity
· Faraday constant
· Oxidation
· Reduction
· Electrolytic refining.

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The Electrochemical Equivalent (Z) is the mass of a substance deposited by one Coulomb of charge. Its value is given by: Z=molar mass/nF

- n = number of electrons transferred per mole of the substance.
- F = Faraday constant (9.65×10^4 C), which is the charge of one mole of electrons.

2. Electrolysis using two electrolytic cells

Even if electrolytic cells are connected, consider electrolysis for each electrolytic cell one by one. Electrons move through the two electrolytic cells.

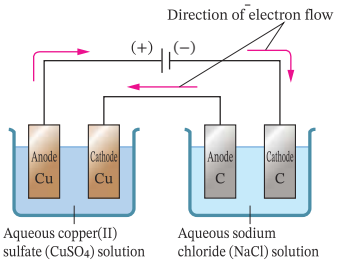

Figure 2.6.1 Electrolysis using two electrolytic cells

(a) Reactions at electrodes (in the case of the figure on the right. 2.6.1)

(i)Reaction in aqueous $CuSO_4$ solution

The electrodes are copper Cu, Cu^{2+} is present in the aqueous solution.

Anode: $Cu \longrightarrow Cu^{2+} + 2e^-$

Cathode: $Cu^{2+} + 2e^- \longrightarrow Cu$

(ii)Reaction in aqueous NaCl solution

The electrodes are carbon, Cl^- and Na^+ are present in the aqueous solution.

Anode: $2Cl^- \longrightarrow Cl_2 + 2e^-$

Cathode: $2H_2O + 2e^- \longrightarrow H_2 + 2OH^-$

(b) Circuit and magnitude of quantity of electricity

When electrolytic cells A and B are connected in series, letting the quantity of electricity flowing through electrolytic cells A and B be Q_A and Q_B, respectively, and the quantity of electricity flowing through the entire circuit be Q, the relationship Q = $Q_A = Q_B$ holds.

Quantity of electricity [C] = Current [A] × Time [s]. In a series circuit, the current flowing through the circuit is the same everywhere.

3. Electrolytic refining of Copper

(a) Electrolytic refining: Obtaining a pure metal from a metal containing impurities using electrolysis.

(b)Electrolytic refining of copper

By smelting chalcopyrite, which is a copper ore, to obtain “impure copper” with a purity of about 99%, and further electrolytically refining it, “pure copper” with a purity of 99.99% or more is obtained.

⟨Mechanism of electrolytic refining of copper⟩ (Figure on the right 2.6.2)

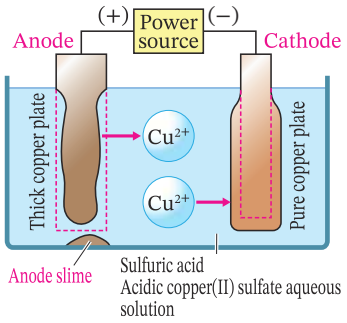

Figure 2.6.2. Electrolytic Refining of Copper

❶ Make the impure copper plate the anode(+) and the pure copper plate the cathode(−) .

❷ At the anode, copper atoms lose electrons and dissolve as copper(II) ions.

Chemical equation: $Cu \longrightarrow Cu^{2+} + 2e^-$

At the cathode, copper(II) ions receive electrons and precipitate as copper.

Chemical equation: $Cu^{2+} + 2e^- \longrightarrow Cu$

❸ At the anode, gold, silver, and other less reactive metals contained in the impure copper precipitate as elements. This precipitate is called anode slime .

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Quantity of electricity — key relations

Relation	Formula
Charge from current & time	Q [C] = I [A] × t [s]
Charge from electrons	Q [C] = F × n(e^-), F = 9.65 × 10^4 C/mol
Cells in series	Q = Q_A = Q_B (same electrons through each cell)
Copper refining	impure Cu = anode (+), pure Cu = cathode (−); Au/Ag → anode slime

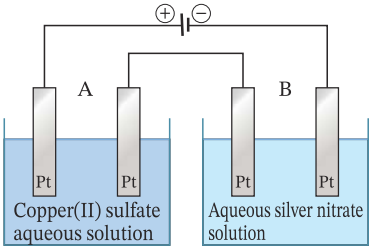
Life Application

Electrolytic refining ensures Better electrical conductivity, Reduced energy loss, More reliable electronic devices Without electrolysis, modern communication systems would not function efficiently.

Warm Up

Answer the following questions

(a) As shown in the figure on the right, an aqueous copper(II) sulfate solution was placed in electrolytic cell A, an aqueous silver nitrate solution in electrolytic cell B, and electrolysis was performed using platinum as electrodes. When a constant current was passed, the mass of the cathode of electrolytic cell B increased by 5.4 g. Assuming the Faraday constant F = 9.65×10^4 C/mol, answer the following questions. Provide answers to two significant figures. (Cu = 64, Ag = 108)

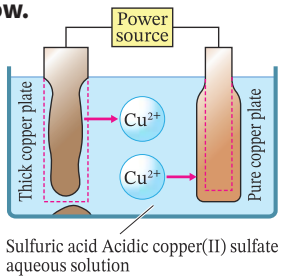


(i)Write the reaction at the cathode of electrolytic cell B as a half-reaction equation.

(ii)What quantity of electricity in C is required for this electrolysis?

(iii)What mass of copper in g was deposited on the cathode of electrolytic cell A?

(b) **Read the following text and answer the questions below.**



Copper extracted from chalcopyrite is called impure copper and contains impurities such as gold, silver, iron, and zinc. By making impure copper the (**A**) electrode and pure copper the (**B**) electrode, electrolysis is performed in an aqueous copper(II) sulfate solution to obtain pure copper. At this time, metals with a (**C**) reactivity such as gold and silver precipitate as elements at the bottom of the electrode, and this precipitate is called (**D**).

(i)Answer the words that apply to A to D.

(ii)Express the reactions at the anode and cathode using half-reaction equations.

Explanation

(a) (i) In the aqueous solution of electrolytic cell B, metal ions of a less reactive metal,

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Ag^+, are present. $\underline{Ag^+ + e^- \longrightarrow Ag}$

(ii) Consider the reaction at the cathode of electrolytic cell B, for which the mass increase is known.

From the reaction equation in (i), it can be seen that when 1 mol of Ag is formed, 1 mol of electrons flows. From the mass increase of the cathode of electrolytic cell B, 5.4 g of Ag is formed, so the amount of substance of Ag formed is

$\frac{5.4\ g}{108\ g/mol} = 5.0\times10^{-2}$ mol

Therefore, the moles of electrons that flowed is also 5.0×10^{-2} mol. Thus, the required quantity of electricity is,

$9.65\times10^{4}\ C/mol \times 5.0\times10^{-2}\ mol = 4.825\times10^{3} \approx 4.8\times10^{3} C$

(iii)The reaction at the cathode of electrolytic cell A is $Cu^{2+} + 2e^- \longrightarrow Cu$.

From the reaction equation, it can be seen that when 1 mol of Cu is formed, 2 mol of electrons flow.

In a series circuit, since the current flowing through the circuit is the same everywhere, the moles of electrons flowing is also the same.

The electrons that flowed into electrolytic cell A are 5.0×10^{-2} mol, and the amount of substance of Cu formed is $5.0\times10^{-2}\times\frac{1}{2}$ mol.

Therefore, the mass of the deposited copper is,

$64\ g/mol \times 5.0\times10^{-2}\times\frac{1}{2}\ mol = 1.6\ g$

(b) (i) **A**: anode **B**: cathode **C**: low **D**: anode slime

(ii) Anode: $Cu \longrightarrow Cu^{2+} + 2e^-$

Cathode: $Cu^{2+} + 2e^- \longrightarrow Cu$

NOS: Identifying variables

A scientist wants to investigate the effect of electric current on the mass of copper deposited during electrolysis.

1. What is the independent variable?

.....

2. What is the dependent variable?

.....

3. Which variables should be controlled to ensure a fair test?

.....

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Try

Choose the correct answer:

1. Which equation directly relates current and time to the quantity of electricity?

A. PV = nRT B. Q = It

C. π = cRT D. Δt = Km

Answer: _____

2. In copper electrorefining, impure copper acts as the:

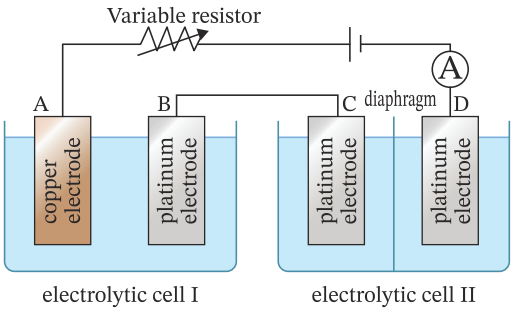
A. Cathode B. Electrolyte

C. Anode D. Salt bridge

Answer: _____

Answer on the following question

3. An electrolytic apparatus was assembled as shown in the figure, and an aqueous copper(II) sulfate solution was placed in electrolytic cell I, and an aqueous sodium sulfate solution in electrolytic cell II. Using this apparatus, electrolysis was performed for 32 minutes and 10 seconds while maintaining the current at 10 A. Answer the following questions. Assume the Faraday constant F = 9.65×10^4 C/mol.



(a) How many moles of electrons flowed?

(b) Express the changes occurring at electrodes A and B using half-reaction equations.

(c) Which is the closest value to the mass change [g] of electrode A in electrolytic cell I after electrolysis? (Cu = 64)

A −19.2 B −12.8 C −6.4 D ±0 E +6.4 F +12.8 G +19.2

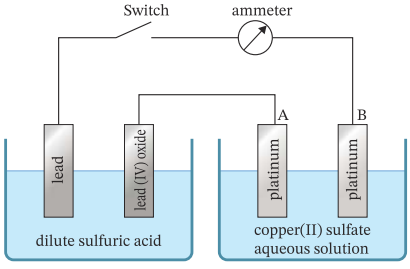
(d) What is the volume in L of the gas generated at electrode C of electrolytic cell II at 0°C and 1.013×10^5 Pa? Answer to two significant figures.

(e) What property does the aqueous solution near electrode D in electrolytic cell II exhibit after electrolysis?

Exercise

Read the following text and answer the questions below. Assume the Faraday constant **F** = *9.65×10^4 C/mol.*
(H = 1.0, O = 16, S = 32, Cu = 64, Pb = 207)

As shown in the figure, a lead-acid battery, an electrolytic cell, and an ammeter were connected in series. The electrolytic cell contains 200 mL of 0.200 mol/L aqueous copper(II) sulfate solution. Platinum plates were used for the electrodes of the electrolytic cell, and electrolysis was performed with a current of 2.00 A for 32 minutes and 10 seconds. In the electrolytic cell, the platinum plate A in the figure acts as the anode, and the platinum plate B acts as the cathode. On electrode B, (i) was deposited.



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The lead-acid battery used for electrolysis is a battery in which dilute sulfuric acid with a density of 1.20 g/cm^3 and a concentration of 30.0% by mass is used, and lead is immersed as the anode (−) and lead(IV) oxide as the cathode (+).

(I)At the lead electrode, a(ii) reaction occurs, and (II)at the lead(IV) oxide electrode, a (iii) reaction occurs. When discharge continues, white (iv) is formed on both electrodes, and the electromotive force decreases. It can be charged by connecting the electrodes of a discharged lead-acid battery to the electrodes of a separate power source and passing electricity.

(a) Choose the appropriate words to enter in ( ) in the text, one by one, from the following words. The same word may be used repeatedly.

Oxidation, Reduction, Copper, Lead, Copper(II) sulfate, Lead(II) sulfate, Copper(II) oxide, Lead(IV) oxide

(b) Write the half-reactions for the underlined parts (I) and (II), showing electron transfer.

(c)Using platinum electrodes, write the half-reaction at electrode A (part 1). Then, when copper electrodes replace the platinum electrodes, write the half-reaction at electrode A (part 2)

(d) Calculate the change in mass of the lead anode (−) of the lead-acid battery, including increase or decrease, to the first decimal place.

Challenge Your Thinking

Two electrolytic cells are connected in series.

• Cell A contains $CuSO_4$ solution.

• Cell B contains $AgNO_3$ solution.

During electrolysis, 10.8 g of silver is deposited in Cell B.

Without directly using the example from the lesson:

1. Determine the moles of silver produced. .....

2. Calculate the moles of electrons transferred. .....

3. Calculate the mass of copper deposited in Cell A.....

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Lesson 2-7 — Rate of Reaction

✨ Engaging Introduction

A piece of iron left outdoors may take months or years to rust, while a tablet dropped into water can begin reacting almost immediately. In industry, some reactions must occur rapidly to increase production, whereas others must be slowed down for safety reasons.

In this lesson, we will explore how reaction rates are measured and how mathematical models help scientists understand the factors that control chemical change.

❓ Guiding question: Why do some chemical reactions occur in seconds while others take days, months, or even years, and how can chemists predict the speed of a reaction?

📌 Point!

1. The Concept of Reaction Rate

Chemical reactions vary widely, ranging from **fast reactions** that complete instantly to **slow reactions** that proceed over a very long time.

• **Example of a fast reaction:** The formation of a white precipitate of silver chloride when an aqueous solution of sodium chloride is added to an aqueous solution of silver nitrate.

• **Example of a slow reaction:** The slow oxidation of iron by atmospheric moisture and oxygen outdoors, leading to the formation of rust.

Even the same reaction can change its rate depending on conditions such as temperature and pressure.

NOS: Identifying variables

Students investigate how temperature affects reaction rate by observing the reaction between an effervescent tablet and water.

1. What is the independent variable?

.....

2. What is the dependent variable?

.....

3. Which variables should be controlled to ensure a fair test?

.....

2. Definition and Expression of Reaction Rate

Rate of Reaction: The decrease in the amount of reactant or the increase in the amount of product per unit time. The change in the amount of substance is usually considered as the change in concentration.

$$\text{Rate of reaction } v = \frac{\text{Amount of decrease in molar concentration of reactants}}{\text{Reaction time}} \text{ or } \frac{\text{Amount of increase in molar concentration of products}}{\text{Reaction time}}$$

structure of science

Key Fact :

Reaction rate depends on reactant concentration and temperature, and its relationship is described by an experimentally determined rate equation.

Key Concepts:

· Reaction rate
· Concentration
· Rate equation
· Rate constant
· Reaction order.

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3. Ratio of Reaction Rates and Stoichiometric Coefficients

Although the change in the molar concentration per unit time differs depending on **the substance focused on in a chemical reaction, the ratio of the rates of reaction for each substance is equal to the ratio of their stoichiometric coefficients in the balanced chemical equation**.

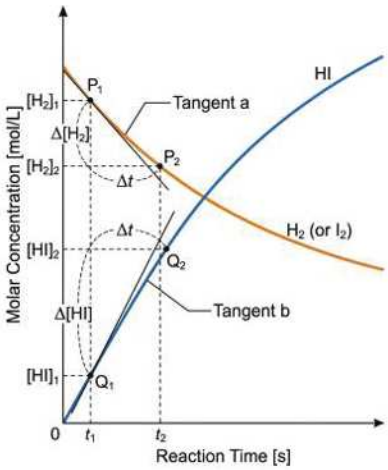

Figure 2.7.1 Reaction Rate and Stoichiometric Coefficients

Example: When hydrogen and iodine are placed in a closed container and heated to a constant temperature, the following reaction occurs, generating hydrogen iodide:

$H_2 + I_2 \rightarrow 2HI$

The rate of disappearance of H_2 or I_2 : the rate of formation of HI = 1 : 2.

4. The Rate Equation

The rate equation expresses the relationship between the rate of reaction and the molar concentrations of the substances involved in the reaction.

For a reaction represented by the chemical equation A + B → C + D, assuming the rate of reaction is v, the molar concentrations of reactants A and B are [A] and [B], and k, a, and b are constants, the rate equation (rate law) can be expressed as follows:

$v = k\,[A]^a\,[B]^b$

• **The Rate Constant** (k): This is the proportionality constant in the rate equation. The value of k is constant if the temperature is constant, but it changes if the temperature changes.

• **The Order of Reaction** (a, b): These are the orders of reaction with respect to reactants A and B, respectively. These values **must be determined experimentally** and do not necessarily match the stoichiometric coefficients in the chemical equation.

📦 Reference table

Quantity	Expression	Notes
Rate of reaction	$v = \frac{-\Delta[\text{reactant}]}{\Delta t} = \frac{+\Delta[\text{product}]}{\Delta t}$	change per unit time; usually as a change in concentration
Rate ratio	rate ∝ stoichiometric coefficient	e.g. for $H_2 + I_2 \rightarrow 2HI$ the rates $H_2 : I_2 : HI = 1 : 1 : 2$
Rate equation (rate law)	$v = k\,[A]^a\,[B]^b$	a, b are reaction orders — found experimentally
Rate constant k	proportionality constant	constant at fixed T; changes when T changes

Life Application

Refrigerators and Freezers: Placing perishable food in the fridge drops the temperature, which significantly slows down the chemical and biological reactions that cause food to spoil or bacteria to multiply.

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Warm Up

Answer the following questions.

(a) Consider the reaction represented by A + B → C. By varying the concentrations of A and B, the instantaneous rate of reaction v was found for each, and the results shown in the table below were obtained.

Answer the questions below.

Experiment	[A] [mol/L]	[B] [mol/L]	v [mol/(L·s)]
1	0.30	1.20	3.6×10^{-2}
2	0.30	0.60	9.0×10^{-3}
3	0.60	0.60	1.8×10^{-2}

(i) Express the relationship between [A], [B], and v as a rate equation, letting the rate constant be k.

(ii) Give the value of the rate constant k to two significant figures.

(b) For a certain reaction, the rate constant doubles when the temperature rises by 10 K near room temperature. In this reaction, when the reaction temperature is changed from 25°C to 55°C, by what factor does the rate v increase?

Explanation

(a)(i) From experiment 1 and experiment 2, when [B] is halved, v becomes $\frac{1}{4}$, so v is proportional to the square of [B].

Also, from experiment 2 and experiment 3, when [A] is doubled, v is doubled, so it can be seen that v is proportional to the first power of [A]. Therefore, $v = k\,[A]\,[B]^2$

(a)(ii) Once the rate equation is determined, the rate constant k can be found from the experimental results.

From the results of experiment 3,

$1.8\times10^{-2}\ \text{mol/(L·s)} = k \times (0.60\ \text{mol/L}) \times (0.60\ \text{mol/L})^2$

$$k = \frac{1.8\times10^{-2}\ \text{mol/(L·s)}}{0.60\ \text{mol/L} \times (0.60\ \text{mol/L})^2}$$

$= 0.0833\ \text{L}^2/(\text{mol}^2\cdot\text{s})$

$\approx 8.3\times10^{-2}\ \text{L}^2/(\text{mol}^2\cdot\text{s})$

Therefore, the value of k is 8.3×10^{-2}

(b) Changing from 25°C to 55°C increases the temperature by 30 K.

Since the rate constant doubles for every 10 K rise in temperature, when the temperature rises by 30 K, the rate constant increases by a factor of $2^3 = 8$.

Therefore, the rate constant becomes 8 times the original value.

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Think Like a Chemist

A pharmaceutical company develops a medicine that decomposes too quickly during storage.

Questions

- Should the medicine be stored at higher or lower temperatures? .....
- Which factors could slow the decomposition reaction? .....
- How could reaction-rate knowledge improve product safety? .....

Try

1. When 10.0 mL of 1.00 mol/L hydrogen peroxide solution is added to a small amount of manganese(IV) oxide, the hydrogen peroxide decomposes and oxygen is generated. The concentration of hydrogen peroxide became 0.64 mol/L 2 minutes after the start of the reaction. Answer the following questions to two significant figures.

(a) What is the rate of decomposition of hydrogen peroxide in mol/(L·s) during this time?

(b) What is the rate of generation of oxygen in mol/s?

Answer: _____

2. For a reaction that forms product C from reactants A and B at 25 °C, the rate of formation of C, v, quadrupled when only (A) was doubled, and decreased to ¼ of its original value when only (B) was halved (½). Answer the following questions.

(a) Letting the rate constant be k, write the rate equation expressing the relationship between v, (A), and (B).

Answer: _____

(b) When both (A) and (B) are doubled, by what factor does v increase?

Answer: _____

3. Consider a reaction where C is formed from A and B. When the rate of formation v [mol/(L·s)] of C was found by changing the molar concentrations [A] and [B], the results in the table below were obtained.

Experiment	[A] [mol/L]	[B] [mol/L]	v [mol/(L·s)]
(i)	0.30	0.60	0.0090
(ii)	0.30	1.20	0.036
(iii)	0.60	0.60	0.018

(a) Write the rate equation expressing the relationship between [A], [B], and v. Assume the proportionality constant is k.

Answer: _____

(b) What is the proportionality constant k called?

Answer: _____

(c) Find the value of the proportionality constant k to two significant figures.

Answer: _____

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Exercise

Choose the correct answer:

1. For the reaction $H_2 + I_2 \rightarrow 2HI$, the rate of formation of HI compared with the rate of disappearance of H_2 is:

A. 1 : 1

B. 2 : 1

C. 1 : 2

D. 4 : 1

Answer: _____

2. Which quantity changes when temperature changes?

A. Reaction order

B. Stoichiometric coefficient

C. Rate constant (k)

D. Balanced equation

Answer: _____

Answer on the following question

3. For a reaction that forms product C from reactants A and B at 25 °C, the rate of formation of C, v, doubled when only [A] was doubled, and decreased to ¼ of its original value when only [B] was halved (½). Answer the following questions.

(a) Write the unit of v. Assume the unit of time is minutes [min].

Answer: _____

(b) Letting the rate constant be k, write the rate equation expressing the relationship between v, [A], and [B].

Answer: _____

(c) When [A] is tripled and [B] is quadrupled, by what factor does v increase?

Answer: _____

Challenge Your Thinking

A reaction follows the rate law: $v = k[A][B]^2$ A student doubles

both reactants simultaneously.

Challenge Questions - By what factor does the reaction rate increase?

Answer: _____

- Which reactant has the greater effect on reaction rate?

Answer: _____

- Predict what would happen if [A] were halved while [B] remained constant.

Answer: _____

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Lesson 2-8 — Factors Affecting the Rate of Reaction

✨ Engaging Introduction

A piece of iron left outdoors rusts slowly over months, while a sparkler burns in seconds. A hydrogen peroxide solution may remain stable in a bottle for weeks, yet it bubbles vigorously when poured onto a wound. Why do some reactions occur almost instantly while others take years?

In this lesson, we will investigate how factors such as concentration, temperature, catalysts, surface area, and light influence the speed of chemical reactions and how scientists use evidence to explain these changes.

❓ **Guiding question**: How can we control the speed of a chemical reaction to make processes safer, faster, and more efficient?

🔬 Inquiry-Based Investigation

Materials

- Effervescent tablets
- Three beakers
- Water at different temperatures (cold, room temperature, hot)
- Stopwatch

Procedure

1. Place equal volumes of water in three beakers.
2. Adjust temperatures to cold, room temperature, and hot.
3. Add identical tablets simultaneously.
4. Measure the time required for each tablet to dissolve completely.

What is your observation?

.....

What is your conclusion?

.....

structure of science

Key Fact :

A chemical reaction occurs only when particles collide with enough energy to overcome the activation energy barrier.

Key Concepts:

· Catalyst
· Homogeneous catalyst
· Heterogeneous catalyst
· Enzyme
· Transition state
· Activation energy

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Point!

1. Factors Affecting the Rate of Reaction

(a) Chemical reactions and collisions of particles

Chemical reactions occur when particles such as atoms, molecules, and ions that make up a substance collide with each other. An increase in the number of particle collisions increases the rate of reaction.

(b) Conditions for changing the rate of reaction

(i) **Concentration:** The higher the concentration of reactants, the greater the rate of reaction.

(ii) **Temperature:** As the temperature increases , the rate of reaction increases significantly.

(iii) **Catalyst:** A substance that increases the rate of reaction without itself undergoing any permanent chemical change.

- **Homogeneous catalyst:** A catalyst that exists in the same phase as the reactants.
- **Heterogeneous catalyst:** A catalyst that exists in a different phase from the reactants.
- **Enzyme:** A catalyst that works within a living organism. Composed of proteins.

(iv) Surface area of solid: Increasing the surface area of a solid increases the rate of reaction.

> **Example:** When the same amount of hydrochloric acid is added to magnesium ribbon and powdered magnesium, hydrogen is generated more vigorously from the powdered magnesium.

(v) Photochemical reaction: Chemical reactions may occur when a substance absorbs light energy.

Problem-Solving

A chemical company wants to increase the production rate of a product without increasing the amount of reactants.

Question

Which modification would most effectively increase the reaction rate?

A. Lower the temperature

B. Add a suitable catalyst

C. Reduce the surface area of reactants

D. Dilute the reactants

Reasoning

write your Reasoning .

.....

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2. Activation energy

(a) **Transition state:** A high-energy state where the rearrangement of atoms occurs. When a chemical reaction proceeds, colliding particles pass through this state.

(b) **Activation energy:** The minimum energy required to bring reactants to the transition state (Figure on the right 2.8.1).

• For a chemical reaction to proceed, particles must collide with energy equal to or greater than the activation energy.

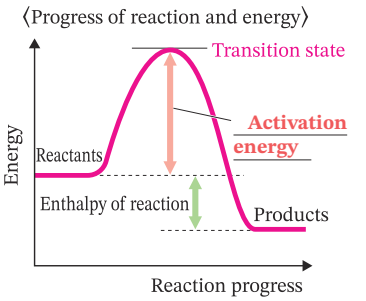


Figure 2.8.1 Activation Energy

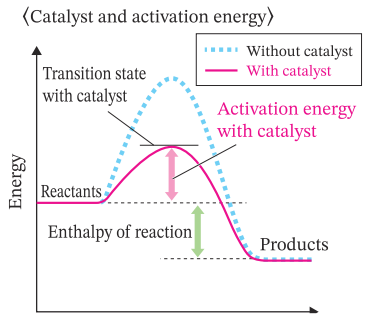


Figure 2.8.2 Catalyst and Activation Energy

(c) **Catalyst and activation energy Figure on the right 2.8.2):**

Using a catalyst increases the rate of reaction.

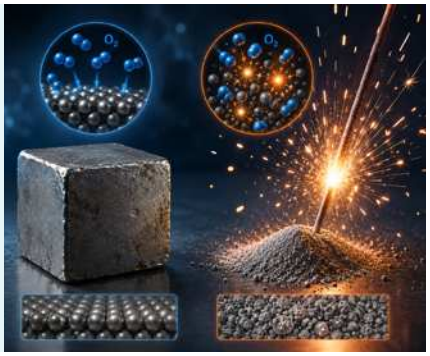
⟨Reason⟩ This is because the catalyst provides an alternative reaction pathway with a lower activation energy, making it easier for reactants to reach the transition state.

📦 Reference table — factors that change the rate

Factor	Effect on rate	Why
Concentration ↑	rate increases	more frequent particle collisions
Temperature ↑	rate increases significantly	more collisions have energy ≥ activation energy
Catalyst	rate increases	provides an alternative path with lower activation energy
Surface area ↑	rate increases	more contact area / more collisions
Light (photochemical)	can start a reaction	substance absorbs light energy

Life Application

When a metal such as iron or aluminum is present as a large solid piece, it reacts relatively slowly with oxygen in the air. However, when the same metal is ground into a fine powder and used in fireworks or sparklers, it burns rapidly and produces bright light, sparks, and heat.



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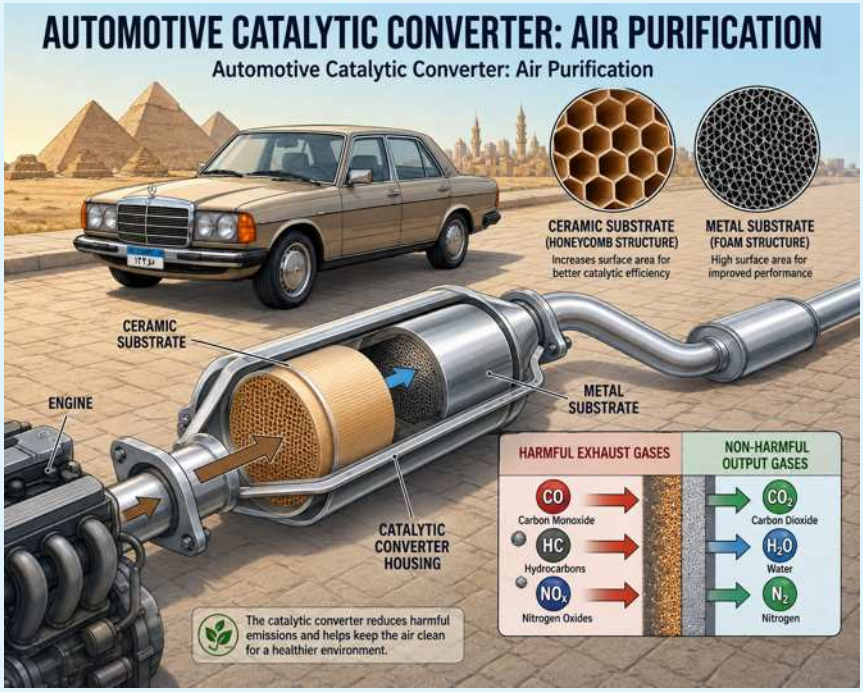
Life Application



Everyday Catalysts: The Three-Way Catalyst in Automobile Exhaust Purification Harmful substances such as carbon monoxide (CO), hydrocarbons, and nitrogen oxides (NO_x) are contained in car exhaust gas. To rapidly convert these into harmless products — carbon dioxide (CO_2), water (H_2O), and nitrogen (N_2) — a **Three-Way Catalyst is** used.

(i) Increasing the Rate of Reaction with a Catalyst Although harmful substances in exhaust gas can naturally react with oxygen to become harmless without a catalyst, the rate of reaction is extremely slow — insufficient to process the continuous stream of gases emitted while driving. The Three-Way Catalyst, which uses noble metals like platinum (Pt) and palladium (Pd), dramatically lowers the required **activation energy**, so the reactions are completed almost instantly and the exhaust gas is purified.

(ii) Why the Honeycomb Structure?

The actual Three-Way Catalyst has a fine, ceramic mesh structure, known as a **Honeycomb Structure** (resembling a beehive), used to maximise the **surface area** of contact between the catalyst and the gases. Since the rate of reaction is proportional to the contact area between the reactants and the catalyst, this structure allows efficient purification of large volumes of exhaust gas within a limited space.

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Warm Up

Answer the following questions.

(a) The following (i) to (iv) describe factors affecting the rate of reaction. For each, choose the most closely related factor from A to E below.

(i) Hydrogen peroxide solution is stored at a low temperature.

(ii) When dilute hydrogen peroxide solution is applied to the skin, no particular change is observed, but when applied to a wound, it foams vigorously.

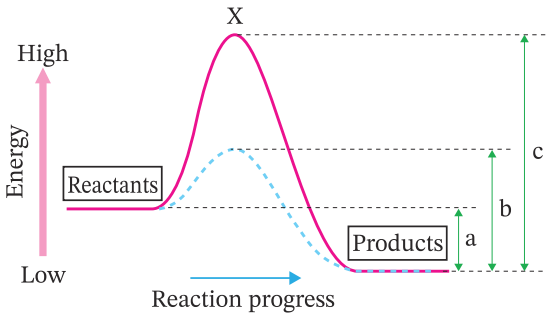
(iii) When a small piece of zinc is placed in 1 mol/L hydrochloric acid and aqueous acetic acid solution respectively, hydrogen gas is produced more rapidly in hydrochloric acid.

(iv) Nitric acid is stored in an amber bottle.

A. Concentration B. Temperature

C. Light D. Catalyst E. Pressure

(b) The figure on the right shows the relationship between the reaction pathway and energy for a certain reaction with and without a catalyst. **Answer the following questions.**



(i) Is this reaction an exothermic reaction or an endothermic reaction?

(ii) What is state X called?

(iii) Express the following values using a to c in the figure.

A. Activation energy without a catalyst

B. Activation energy with a catalyst

C. Enthalpy of reaction with a catalyst

Explanation

(a)(i) Since the rate of reaction increases when the temperature is high, it is kept at a low temperature to make the reaction less likely to occur. **B**

(ii) When applied to a wound, enzymes present in living tissues act as catalysts, significantly increasing the rate of reaction. **D**

(iii) Since hydrogen chloride is a strong acid and acetic acid is a weak acid, the hydrogen ion concentration [H^+] is greater in hydrochloric acid, resulting in a greater rate of formation of hydrogen. **A**

(iv) Since nitric acid is easily decomposed by light, it is stored in a light-shielding amber bottle. **C**

(b)(i) From the figure, the energy decreases due to the reaction. A decrease in energy indicates an exothermic reaction, which releases energy during the reaction.

(ii) Transition state.

(iii) The solid line with the higher activation energy represents the reaction without a catalyst, and the dashed line represents the reaction with a catalyst.

A: The activation energy is the difference between the energy possessed by the

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reactants and the energy at the

transition state. Therefore, c−a

B: b−a

C: The enthalpy of reaction is the difference in energy between the reactants and the products.

Also, since the energy possessed by the products is smaller than the energy possessed by the reactants, the sign is negative. −a .

Try

1. Two identical reactions are performed. In Experiment A, powdered calcium carbonate is used; in Experiment B, large marble chips are used. Which statement best explains why Experiment A is faster?

A. Powder has lower activation energy.

B. Powder has greater surface area.

C. Powder increases temperature.

D. Powder acts as a catalyst.

Answer: _____

2. A reaction becomes four times faster when the temperature is increased. Which explanation is most accurate?

A. More particles are created.

B. More collisions have sufficient energy to react.

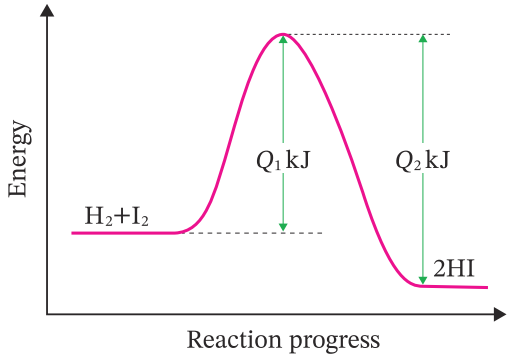
C. Activation energy increases.

D. Reactants disappear instantly.

Answer: _____

3. Read the following text and answer the questions below.

The figure on the right shows the energy change of the reaction in which hydrogen iodide HI is formed from hydrogen H_2 and iodine I_2. The activation energy for the formation of hydrogen iodide is (**A**) kJ, the enthalpy of reaction is (**B**) kJ, the activation energy for the decomposition of hydrogen iodide is (**C**) kJ, and the enthalpy of reaction is (**D**) kJ. When a catalyst is added to increase the rate of reaction, the activation energy of the formation reaction (**E**). At this time, the enthalpy of reaction for the formation (**F**).



(a) Choose appropriate symbols or words for A to F in the text from (i) to (vii) below.

(i) Q_1 (ii) Q_2 (iii) Q_1-Q_2 (iv) Q_2-Q_1

(v) Increases (vi) Decreases (vii) Does not change

(b) As stated in the underlined part, adding a catalyst increases the rate of reaction. Explain the reason for this.

Answer: _____

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🛠️ Engineering Design Challenge

Design a simple investigation to determine which factor has the greatest effect on the rate of dissolving an effervescent tablet:

• Temperature

• Surface area

• Concentration

Students must:

1. Form a hypothesis.

Answer: _____

2. Identify variables.

Answer: _____

3. Collect data.

Answer: _____

4. Put conclusions using evidence.

Answer: _____

Exercise

1. For each statement regarding the rate of reaction, choose the factor from the word bank below that is most closely related to the statement. The same factor may be chosen multiple times.

(a) Wood burns more rapidly when it is split into small pieces.

(b) Concentrated nitric acid is stored in an amber bottle.

(c) When a small amount of aqueous iron(III) chloride solution is added to hydrogen peroxide solution, oxygen is generated rapidly.

(d) When equal masses of zinc are added to 10 mL each of 1 mol/L hydrochloric acid and acetic acid, hydrogen is generated more rapidly in the hydrochloric acid.

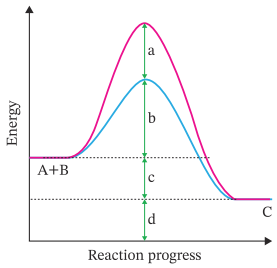
(e) An incense stick burns faster in oxygen than in air.

(f) Hydrogen peroxide is better stored in a refrigerator if possible.

[Word bank: Temperature, Concentration, Pressure, Surface area, Catalyst, Light]

Answer: _____

2. The figure shows the change in the transition state for the reaction A + B ⟶ C with and without a catalyst. Answer the following questions.



(a)Express the following energies using the symbols a to d in the figure.

(i)Activation energy of A + B ⟶ C without a catalyst

(ii)Activation energy of A + B ⟶ C with a catalyst

(iii)Activation energy when the reaction C ⟶ A + B occurs without a catalyst

(iv)Enthalpy of reaction when the reaction A + B ⟶ C occurs

(b)Is the reaction A + B ⟶ C an exothermic reaction or an endothermic reaction?

Answer: _____

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Lesson 2-9 — Chemical Equilibrium

✨ Engaging Introduction

Imagine opening a bottle of carbonated soft drink. As soon as the bottle is opened, bubbles begin to escape. If the bottle remains closed, carbon dioxide stays dissolved in the drink. Why does the system behave differently when conditions change?

Similarly, in our bodies, oxygen continuously binds to and releases from hemoglobin, allowing oxygen transport to tissues. These processes involve reactions that proceed in both directions and eventually reach a balance called **chemical equilibrium**.

In this lesson, we will explore how reversible reactions reach equilibrium and how chemists use equilibrium concepts to predict and control chemical systems.

❓ **Guiding question:** How can a chemical reaction appear to stop while reactants and products continue to react?

🔭 Exploration

A student places a sample of brown nitrogen dioxide gas (NO_2) in a sealed transparent syringe . At first, the gas appears dark brown. After some time,

What is your observation?

.....

when the gas in compressed?

.....

What is your Prediction?

If the temperature changes, the equilibrium position may shift, changing the color intensity again.?

.....

📌 Point!

1. Reversible and irreversible Reactions

(a) **Reversible reaction:** A reaction that proceeds in both directions. Expressed using a double arrow "$\rightleftharpoons$"

Example: When hydrogen and iodine are heated, hydrogen iodide is formed. Conversely, when hydrogen iodide is heated, it decomposes into hydrogen and iodine.
$H_2 + I_2 \rightleftharpoons 2HI$

• In a reversible reaction, the reaction proceeding to the right is called the forward reaction, and the reaction proceeding to the left is called the backward reaction.

(b) **Irreversible reaction:** A reaction that proceeds only in one direction. Expressed using a single arrow "$\longrightarrow$".

⭐ **structure of science**

Key Fact :

At chemical equilibrium, the forward and reverse reactions continue to occur, but at equal rates, causing concentrations to remain constant.

Key Concepts:

· Reversible reaction
· Irreversible reaction
· Dynamic equilibrium
· Equilibrium constant (K)
· Forward reaction
· Reverse reaction.

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Example: When steel wool is heated, iron(II) oxide FeO is formed, but the reverse reaction does not occur. $2Fe + O_2 \rightarrow 2FeO$

2. Chemical Equilibrium

(a) **State of chemical equilibrium (Equilibrium state):** A state where the rates of the forward and reverse reactions become equal, and the concentrations of reactants and products remain constant.

(b) **Law of chemical equilibrium (Law of mass action)**

• For reactants A, B and products C, D, when the reversible reaction $aA + bB \rightleftharpoons cC + dD$ is in an equilibrium state, the following relationship holds among the concentrations [A], [B], [C], and [D] of each substance.

$$\frac{[C]^c[D]^d}{[A]^a[B]^b} = K \text{ (constant)}$$

Note: K in this equation is called the **equilibrium constant** of chemical equilibrium, and it is constant as long as the temperature does not change.

- The equilibrium constant in reactions between solids and gases is expressed only by the concentration of the gases.

  This is because the concentrations of pure solid substances remain constant and do not affect the equilibrium expression.

  Example: The equilibrium constant K in the reaction $C(s) + CO_2(g) \rightleftharpoons 2CO(g)$ is as follows.

  $$K = \frac{[CO]^2}{[CO_2]}$$

- The unit of the equilibrium constant is determined by calculating the units together.

  Example: The unit of $K = \frac{[B]}{[A]^3}$ is $[(mol/L)^{-2}]$.

(c)Calculating the Equilibrium Constant

1. Write the balanced chemical equation and record the initial amount of substance (or concentration) of each reactant and product.
2. Determine the change in the amount of substance (or concentration) of each substance as the reaction proceeds toward equilibrium.
3. Calculate the amount of substance (or concentration) of each substance at equilibrium.
4. Substitute the equilibrium concentrations into the equilibrium constant expression and calculate the equilibrium constant.

	N_2O_4	$2NO_2$	
1 Initial	0.50	0	[mol]
2 Change	−0.30	+0.60	[mol]
3 Equilibrium	0.20	0.60	[mol]

4 Equilibrium constant $K = \frac{\left(\frac{0.60\ mol}{10\ L}\right)^2}{\left(\frac{0.20\ mol}{10\ L}\right)}$

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Think Critically

Analyze Experimental Data

Scientists often increase the pressure in the Haber Process to produce more ammonia.

If increasing pressure requires more energy and higher costs, how should engineers decide whether the increase in ammonia production is worth the extra cost?

.....

.....

.....

Warm Up

When 5.50 mol of hydrogen and 4.00 mol of iodine are placed in a 100 L container and kept at a certain temperature, the reaction below occurs, reaching an equilibrium state. At this time, 7.00 mol of hydrogen iodide was formed. Answer the following questions.

$H_2 + I_2 \rightleftharpoons 2HI$

(a) Calculate the equilibrium constant for this reaction to two significant figures.

(b) When 3.00 mol of hydrogen and 3.00 mol of iodine are placed in the same container and kept at the same temperature as in (a), how many moles of hydrogen iodide will be formed? Give your answer to two significant figures.

Explanation

(a) It is helpful to write the balanced chemical equation and construct a reaction table.

	H_2	+ I_2	$\rightleftharpoons$ $2HI$	
Initial	5.50	4.00	0	[mol]
Change	−3.50	−3.50	+7.00	[mol]
Equilibrium	2.00	0.50	7.00	[mol]

The equilibrium constant $K = \frac{[HI]^2}{[H_2][I_2]}$, and since the size of the container is 100 L, the equilibrium constant of this reaction is,

$$\frac{\left(\frac{7.00\ \text{mol}}{100\ \text{L}}\right)^2}{\left(\frac{2.00\ \text{mol}}{100\ \text{L}}\right) \times \left(\frac{0.50\ \text{mol}}{100\ \text{L}}\right)} = \underline{49}$$

(b) Assuming that x mol each of H_2 and I_2 react to reach equilibrium, the amounts of substance are as follows.

Be Global Citizen

Increasing atmospheric carbon dioxide dissolves in oceans and affects the equilibrium of carbonate ions needed by corals and shellfish.

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	H_2	+	I_2	$\rightleftharpoons$	2HI	
Initial	3.00		3.00		0	[mol]
Change	−x		−x		+2x	[mol]
Equilibrium	3.00−x		3.00−x		2x	[mol]

Since the equilibrium constant is constant at the same temperature, from (a), the equilibrium constant is 49. Therefore,

$$\frac{\left(\frac{2x\ [\text{mol}]}{100\ \text{L}}\right)^2}{\left(\frac{3.00-x\ [\text{mol}]}{100\ \text{L}}\right)\times\left(\frac{3.00-x\ [\text{mol}]}{100\ \text{L}}\right)} = 49$$

$$\frac{(2x)^2}{(3.00-x)^2} = 49$$

$$\frac{2x}{3.00-x} = \pm 7$$

$$x = 2.33\ \text{mol}, 4.2\ \text{mol}$$

Since the initial amounts of hydrogen and iodine are 3.00 mol, x must be less than 3.00 mol ($0 < x < 3.00$). Therefore,
$x = 2.33$ mol

Therefore, the hydrogen iodide formed at equilibrium is $2.33\times2 = 4.66 \approx 4.7$ mol 4.7 mol

Try

Solve the Following Questions

1. A mixture of 1.00 mol of acetic acid and 1.00 mol of ethanol reacts at a constant temperature. At equilibrium, 0.25 mol of acetic acid remains. Give your answers to two significant figures.

$CH_3COOH + C_2H_5OH \rightleftharpoons CH_3COOC_2H_5 + H_2O$

(a) Calculate the equilibrium constant for this reaction.

Answer: _____

(b) When a mixture of 1.00 mol of acetic acid, 1.00 mol of ethanol, and 4.00 mol of water is reacted and reaches equilibrium at the same temperature, how many moles of ethyl acetate $CH_3COOC_2H_5$ are formed?

Answer: _____

2. A mixture of 1.00 mol of H_2 and 1.00 mol of I_2 is placed in a container of constant volume at a constant temperature. At equilibrium, 1.6 mol of HI is present. Give your answers to two significant figures.

(a) Calculate the equilibrium constant for this reaction.

Answer: _____

(b) When 1.6 mol each of H_2 and I_2 are placed in a container of constant volume at the same temperature, determine the amount of substance of HI at equilibrium.

Answer: _____

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Exercise

Choose the correct answer:

1. For the reaction $N_2O_4 \rightleftharpoons 2NO_2$, the equilibrium constant K is correctly written as:

A. $K = [N_2O_4]/[NO_2]^2$

B. $K = [NO_2]^2/[N_2O_4]$

C. $K = [NO_2]/[N_2O_4]$

D. $K = [N_2O_4]/[NO_2]$

Answer: _____

2. A soft drink bottle is opened and bubbles rapidly form. Which explanation is most accurate?

A. Equilibrium shifts as pressure decreases.

B. Water becomes a catalyst.

C. The reaction becomes irreversible.

D. The temperature increases

Answer: _____

Answer on the Following Questions

3. For the following reactions, write the equilibrium constant expression in terms of molar concentrations. Also, state the units of the equilibrium constant if applicable. Assume all substances are gases unless otherwise specified.

(a) $N_2 + O_2 \rightleftharpoons 2NO$

(b) $N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$

(c) $CO_2 + H_2 \rightleftharpoons CO + H_2O$

(d) $C_{(s)} + H_2O \rightleftharpoons CO + H_2$

4. When acetic acid CH_3COOH and ethanol C_2H_5OH react in the presence of concentrated sulfuric acid as a catalyst, ethyl acetate $CH_3COOC_2H_5$ and water are formed, and the system reaches equilibrium. Answer the questions below to two significant figures.

$CH_3COOH + C_2H_5OH \rightleftharpoons CH_3COOC_2H_5 + H_2O$

(a) When 5.0 mol of acetic acid and 8.0 mol of ethanol are mixed and reacted, the equilibrium state is reached, and 4.0 mol of ethyl acetate is formed. Calculate the equilibrium constant, K, for this reaction.

Answer: _____

(b) Under the same temperature as (a), when 8.0 mol of acetic acid and 8.0 mol of ethanol are mixed and reacted, how many moles of ethyl acetate are formed?

Answer: _____

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Lesson 2-10 — Le Chatelier's Principle

✨ Engaging Introduction

Ammonia is one of the world's most important chemicals because it is used to manufacture fertilizers that help feed billions of people.

Scientists discovered that increasing pressure in the reaction:

$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$

produces more ammonia.

If the pressure inside the reaction vessel is suddenly increased, what do you predict will happen to the amount of ammonia produced? Explain your reasoning.

❓ **Guiding question:** How do changes in concentration, pressure, temperature, and catalysts affect chemical equilibrium?

🌎 Exploration

A fertilizer factory produces ammonia using nitrogen and hydrogen gases. Engineers notice that increasing pressure inside the reactor dramatically increases ammonia production, while increasing temperature reduces the amount produced.

Predict

Before studying Le Chatelier's Principle:

What do you think will happen to ammonia production if:

1. More nitrogen gas is added?

.....

2. The pressure is doubled?

.....

3. The temperature is increased?

.....

📌 Point!

1. Direction of equilibrium shift

Le Chatelier's principle:

When a reversible reaction is in an equilibrium state, if conditions such as concentration, pressure, and temperature are changed, the equilibrium shifts in a direction that counteracts the effect, reaching a new equilibrium state.

(a) Effect of Concentration:

When the concentration of a certain component increases, the equilibrium shifts in the direction that **decreases** its concentration.

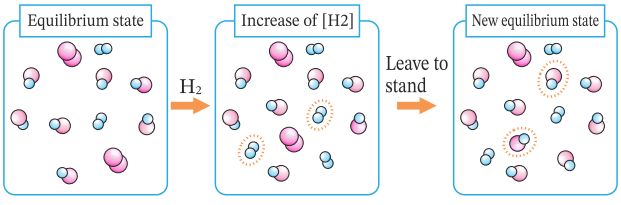

Figure2.10.1 the effect of Concentration

⭐ **structure of science**

Key Fact :

A chemical equilibrium shifts in the direction that opposes any change imposed on the system.

Key Concepts:

· Reversible reactions
· Chemical equilibrium
· Equilibrium shift
· Concentration
· Pressure
· Temperature
· Catalyst

Key law

— Le Chatelier's Principle.

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Example: For the equilibrium system $H_2 + I_2 \rightleftharpoons 2HI$, if $[H_2]$ increases under a constant temperature, it will eventually reach a new equilibrium state by decreasing $[H_2]$. ⇒ The equilibrium shifts to the **right**. (Figure 2.10.1)

(b) Effect of Pressure:

When the pressure of a mixed gas increases, the equilibrium shifts in the direction where the total number of gas molecules **decreases**. (Figure 2.10.2)

In a reaction where the total number of gas molecules does not change before and after the reaction, the equilibrium **does not shift**.

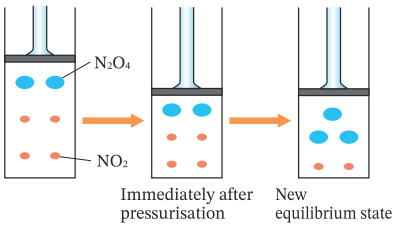

Figure 2.10.2 the effect of Pressure

(c) Effect of Temperature:

When the temperature is lowered, the equilibrium shifts in the direction of the **exothermic reaction**, and when the temperature is raised, the equilibrium shifts in the direction of the **endothermic reaction**.

(d) Effect of a Catalyst: Using a catalyst shortens the time required to reach the equilibrium state, but the equilibrium **does not shift**.

(e) Effect of an Inert Gas (Figure 2.10.3)

When the reversible reaction $2NO_2 \rightleftharpoons N_2O_4$ is in an equilibrium state,

(i) Argon Ar is added at a constant temperature and volume When the volume is constant, the concentration and partial pressure of the substances involved in the reaction do not change.
⇒ The equilibrium does not shift .

(ii) Argon Ar is added at a constant temperature and total pressure When the total pressure is constant, the volume increases by the amount of Ar added, so the partial pressure of the gases involved in the reaction inside the container decreases.

⇒ The equilibrium shifts to the left .

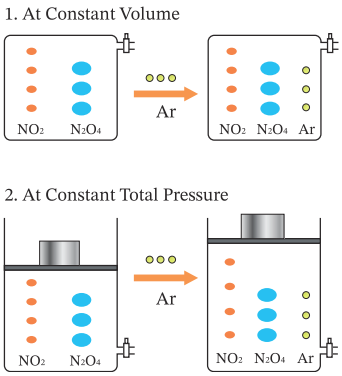

Figure 2.10.3
The effect of an Inert Gas

2. Synthesis of ammonia

The reaction to synthesize ammonia,

$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$ $\Delta H = -92$ kJ,

is an exothermic reaction in which the total number of molecules decreases .

⇒ By making the pressure high and the temperature low , the equilibrium shifts to the right, and the yield of ammonia increases. (Figure 2.10.4).

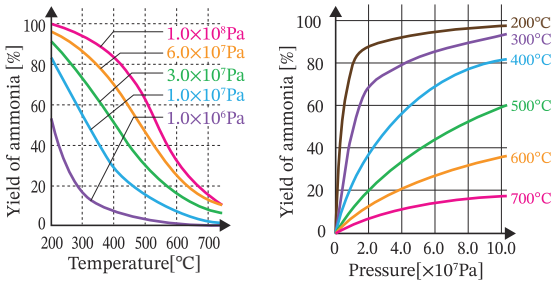

Figure 2.10.4 Synthesis of ammonia

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Life Application

Ammonia Production (Haber Process)

The global production of fertilizers depends on controlling equilibrium conditions to maximize ammonia yield. Without equilibrium control, modern agriculture could not produce enough food for the world's growing population.

Warm Up

Answer the following questions.

(a) For each of the following systems at equilibrium, in which direction will the equilibrium shift when subjected to the indicated change? Answer with the symbols (A) Left, (B) Right, (C) Does not shift.

(i) $3O_2 \rightleftharpoons 2O_3$ (Adding oxygen)

(ii) $2SO_2 + O_2 \rightleftharpoons 2SO_3$ (Adding a catalyst)

(iii) $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$ (Adding ammonium chloride)

(b) In the synthesis of ammonia (an exothermic reaction), a low temperature is favorable for shifting the equilibrium position to the right. However, the actual industrial manufacturing process is carried out at a high temperature of approximately 400–500°C. Explain the reason for this in terms of the rate of reaction.

Explanation

(a) (i) When oxygen is added, the concentration of oxygen increases, so the equilibrium shifts in the direction that decreases the concentration of oxygen. Therefore, the equilibrium shifts to the right. **(B)**

(ii) Even if a catalyst is added, the equilibrium does not shift. **(C)**

(iii) When ammonium chloride is added, it ionizes in the aqueous solution, increasing the concentration of ammonium ions. The equilibrium then shifts in the direction that consumes the added ammonium ions. The equilibrium shifts to the left. **(A)**

(b) If the temperature is too low, the rate of reaction is too small, and the product cannot be obtained within a practical timeframe.

NOS: Identifying variables

A student wants to investigate the effect of temperature on ammonia equilibrium.

1. What is the independent variable? .....

2. What is the dependent variable? .....

3. Which variables should be controlled to ensure a fair test?.....

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Try

Answer on the Following Questions

1. For each of the following equilibrium reactions, determine the direction of the shift in equilibrium position when the condition change shown in ( ) is applied. Answer with "Right", "Left", or „Does not shift".

(a) $H^+ + OH^- \rightleftharpoons H_2O_{(l)}$ $\Delta H = -56$ kJ (Cooling)

(b) $CO + 2H_2 \rightleftharpoons CH_3OH_{(g)}$ (Increasing the pressure)

(c) $CO + 2H_2 \rightleftharpoons CH_3OH_{(g)}$ (Adding a catalyst)

(d) $N_2 + 3H_2 \rightleftharpoons 2NH_3$ (Adding Ar at constant volume)

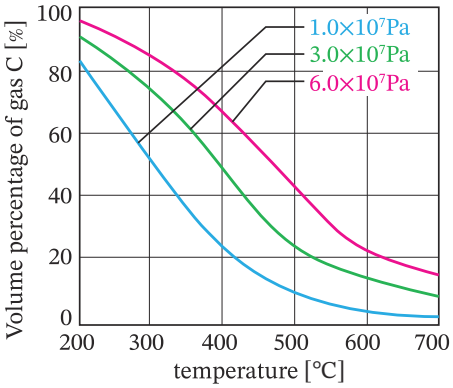
(e) $N_2 + 3H_2 \rightleftharpoons 2NH_3$ (Adding Ar at constant pressure)

(f) $AgCl_{(s)} \rightleftharpoons Ag^+ + Cl^-$ (Adding $HCl_{(g)}$)

2. Consider the following chemical equilibrium involving gases A, B, and C:

$aA + bB \rightleftharpoons cC$ (a, b, and c are coefficients)

The relationship between the volume percentage of C and temperature in the equilibrium state of this reaction is as shown in the figure on the right. Answer the following questions.



(a) Which of the following relationships is correct?

A a+b<c **B** a+b>c **C** a+b=c

Answer: _____

(b) Is the forward reaction of this reaction an exothermic or endothermic reaction?

Answer: _____

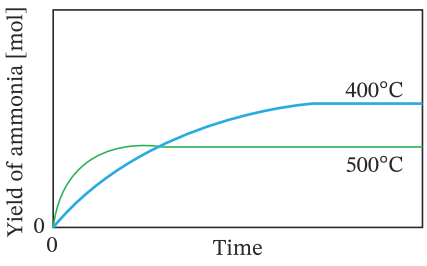
(c) As the temperature is raised, how does the equilibrium constant K of this reaction change?

Answer: _____

3. Ammonia is synthesized from nitrogen and hydrogen by the following reaction.

$N_2 + 3H_2 \rightleftharpoons 2NH_3$

When 1 mol of nitrogen and 3 mol of hydrogen react at a constant pressure in the presence of an iron-based catalyst, the amount of ammonia produced increases until equilibrium is reached. The change in the amount of ammonia formed over time at 400 °C and 500 °C is shown by solid lines in the figure. With reference to this figure, choose one correct statement from the following.



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A. The formation reaction of ammonia is an endothermic reaction.

B. The equilibrium constant of the above chemical equation at 500°C is smaller than the value at 400°C.

C. The rate at which ammonia is formed increases over time at both 400°C and 500°C.

D. When experimenting at a higher pressure, the rate of reaction increases, but the amount of ammonia formed at equilibrium decreases.

Exercise

Answer on the Following Questions

1. For each of the following equilibrium reactions, determine the direction of the shift when the condition change shown in ( ) is applied. Answer with „Right", „Left", or „Does not shift". *Note: (g) = gas, (l) = liquid, (s) = solid, (aq) = aqueous solution; ΔH = enthalpy change.*

(a) $2HI \rightleftharpoons H_2 + I_{2(g)}$ (Adding HI)

(b) $2NO_2 \rightleftharpoons N_2O_4$ (Removing NO_2)

(c) $2HI \rightleftharpoons H_2 + I_{2(g)}$ $\Delta H = 9$ kJ (Raising the temperature)

(d) $2NO_2 \rightleftharpoons N_2O_4$ $\Delta H = -57$ kJ (Lowering the temperature)

(e) $2HI \rightleftharpoons H_2 + I_{2(g)}$ (Increasing the pressure)

(f) $2SO_2 + O_2 \rightleftharpoons 2SO_3$ (Adding Ar at constant pressure)

(g) $C_{(s)} + H_2O_{(g)} \rightleftharpoons CO + H_2$ (Increasing the pressure)

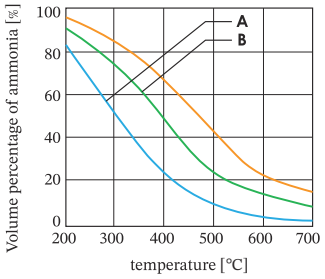
(h) $2SO_2 + O_2 \rightleftharpoons 2SO_3$ (Adding a catalyst)

Answer: _____

2. The following chemical equation is the formation reaction of ammonia.

$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$

When a mixed gas of nitrogen and hydrogen at a ratio of 1 : 3 was reacted under 1.0×10^7 Pa, 3.0×10^7 Pa, and 6.0×10^7 Pa at various temperatures, the results shown in the right figure were obtained. Answer the following questions.



(a) Determine the pressure in Pa represented by curves A and B in the figure, respectively.

Answer: _____

(b) Based on the figure, is the formation of ammonia exothermic or endothermic?

Answer: _____

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Lesson 2-11 — Ionisation Equilibrium

✨ Engaging Introduction

Imagine opening two bottles of clear liquid. Both look like pure water, yet when you insert an electrical conductivity tester, one solution makes the bulb glow brightly while the other produces only a faint light. In another case, a third solution shows no electrical response at all, even though it completely dissolves in water.

In this lesson, we will explore how chemists use ion formation and equilibrium concepts to explain why solutions conduct electricity differently and how these invisible processes determine the behavior of matter in water.

❓ **Guiding question:** How can scientists explain and predict the electrical behavior of solutions based on the extent of ion formation in water?

Exploration

Strong, Weak, or Non-Electrolyte?

Consider the following substances dissolved in water:

• Hydrochloric acid (HCl)

• Acetic acid (CH_3COOH)

• Glucose ($C_6H_{12}O_6$)

Without studying the lesson:

• Which substance will produce the highest number of ions? .....

• Which substance will not produce ions? .....

• Which will produce a weak electrical current? .....

Record your initial ideas and revisit them after studying electrolytes and ionization equilibrium.

.....

📌 Point!

1. The Nature of Electrolytes: Strong and Weak Electrolytes

When a substance dissolves in water, the phenomenon where it separates into ions is called **dissociation** (or **ionisation**). Substances are broadly classified into two groups based on their extent of dissociation, known as the **degree of dissociation** (alpha, α).

• **Strong Electrolytes** (Strong Acids and Strong Bases): substances like hydrogen chloride (HCl) and sodium hydroxide (NaOH) that dissociate almost completely into ions in aqueous solution. For calculation purposes, $\alpha \approx 1$.

• **Weak Electrolytes** (Weak Acids and Weak Bases): substances like acetic acid (CH_3COOH) and ammonia (NH_3). Only a fraction of their molecules turn into ions, while the majority remain as molecules.

structure of science

Key Fact :

Strong electrolytes dissociate completely into ions in aqueous solutions. • Weak electrolytes partially dissociate and establish equilibrium in water. • Electrical conductivity depends on the number of free ions in solution.

Key Concepts:

· Dissociation
· Ionization
· Electrolyte
· Strong electrolyte
· Weak electrolyte
· Degree of dissociation (α)
· Dynamic equilibrium
· Dissociation constant (K_a)
· Ionic conductivity
· Ion mobility
· Solvation

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2. Dissociation Equilibrium as a Reversible Reaction

When a weak electrolyte is dissolved in water, two simultaneous reactions occur: the **forward reaction** (molecules forming ions) and the **reverse reaction** (ions reforming molecules). Eventually, the rates of both reactions become equal, and the apparent change stops. This condition is called **dissociation equilibrium**.

For example, the dissociation equilibrium of acetic acid can be described as follows:

$CH_3COOH \leftrightarrows CH_3COO^- + H^+$

In this state of equilibrium, provided the temperature is constant, the following _ Dissociation Constant (Ka) is established.

$$K_a = \frac{[CH_3COO^-][H^+]}{[CH_3COOH]}$$

Note: K_a is a constant that depends only on temperature and does not change with concentration.-----

Let us mathematically prove why the degree of dissociation (α) increases when the concentration is diluted:

Substance	Initial Conc.	Change in Conc.	Equilibrium Conc.
CH_3COOH	c	−cα	c (1−α)
CH_3COO^-	0	+cα	cα
H^+	0	+cα	cα

Substituting these into the K_a expression:

$$K_a = \frac{[CH_3COO^-][H^+]}{[CH_3COOH]} = \frac{c\alpha \times c\alpha}{c\,(1-\alpha)} = \frac{c\alpha^2}{1-\alpha}$$

Since α is extremely small compared to 1 for a weak acid ($\alpha << 1$), we can make the approximation that $1-\alpha \approx 1$.

Thus, $K_a \approx c\alpha^2$, which rearranges to $\alpha = \sqrt{\frac{K_a}{c}}$

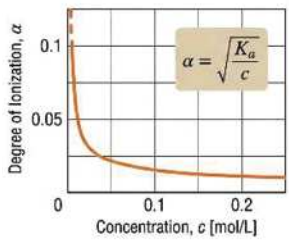

figure 2.11.1 Relationship between Acetic Acid Concentration and Degree of Ionization (calculated values)

This equation demonstrates that the smaller the concentration c (i.e., the more dilute the solution), the larger the degree of dissociation α becomes.

Think Critically

A student claims:

"Acetic acid is a weak acid because it does not dissolve well in water."

Claim–Evidence–Reasoning

Students evaluate:

- Is the claim scientifically valid?.....
- What is the difference between solubility and ionization? .....
- Can a substance be highly soluble but still weakly ionized? Explain.....

3. The Ionic Product of Water (Kw) and its Relation to Temperature

Even pure water dissociates to a very small extent.

$H_2O \leftrightarrows H^+ + OH^-$

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The Ionic Product of Water (K_w) is derived from this equilibrium.

$K_w = [H^+][OH^-] = 1.0\times10^{-14}\ (mol/L)^2$ (at 25°C)

It is important to note that the dissociation of water is an endothermic reaction. According to Le Chatelier's Principle, increasing the temperature shifts the equilibrium to the right, which is the direction that promotes dissociation. This means that as the temperature rises, the value of K_w increases. Consequently, even a neutral solution will have a $[H^+]$ concentration greater than 1.0×10^{-7} mol/L, resulting in a pH value less than 7..

4. Definition of pH

PH is a concise way to express the strength of acidity or basicity using base−10 logarithms.

pH = $-\log_{10}[H^+]$

Note:

For a basic (alkaline) solution, the usual procedure is to first calculate $[OH^-]$ and then use the relationship $K_w = [H^+][OH^-]$ to find $[H^+]$. Alternatively, you may calculate pOH = $-\log_{10}[OH^-]$ and then use the relationship pH + pOH = 14 (at 25°C).

Life Application

Ionization equilibrium in Real Life

The concept of electrolytes is essential in:

- Human nerve signal transmission (ionic movement in cells)
- Medical saline solutions (controlled ion concentration)
- Batteries and electrochemical cells
- Industrial electrolysis processes

Weak and strong electrolytes determine how efficiently charge moves in biological and industrial systems

Warm Up

Answer the following questions:

(a) Calculate the pH of a 0.10 mol/L aqueous acetic acid solution (degree of dissociation 0.016) to one decimal place. ($\log_{10} 1.6 = 0.2$)

(b) Consider a 0.020 M aqueous solution of ammonia at 25°C. Assume the dissociation constant of ammonia is $K = 1.8\times10^{-5}$ mol/L and the ionic product of water is $Kw = 1.0\times10^{-14}$ mol^2/L^2. ($\log_{10} 2.0 = 0.30$, $\log_{10} 3.0 = 0.48$)

(i) Calculate the degree of dissociation of the aqueous ammonia.

(ii) Calculate the hydroxide ion concentration.

(iii) Calculate the pH to one decimal place.

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Explanation

(a) Since pH = $-\log_{10}[H^+]$, first find the hydrogen ion concentration $[H^+]$.

Since acetic acid (CH_3COOH) is a monoprotic acid, $[H^+]$ = molar concentration of acid × degree of dissociation.

Therefore, $[H^+] = 1\times0.10\ \text{mol/L}\times0.016 = 1.6\times10^{-3}\ \text{mol/L}$

Therefore, $\text{pH} = -\log_{10}[H^+] = -\log_{10}(1.6\times10^{-3}) = -(\log_{10}1.6+\log_{10}10^{-3}) = -(0.2-3) = 2.8$

(b) (i) Let α be the degree of dissociation. Using the initial concentration C and the dissociation constant K, from the relationship

$$\alpha = \sqrt{\frac{K}{C}},$$

$$\alpha = \sqrt{\frac{1.8\times10^{-5}\ \text{mol/L}}{0.020\ \text{mol/L}}} = \sqrt{9.0\times10^{-4}} = \underline{3.0\times10^{-2}}$$

(ii) Since ammonia (NH_3) produces one hydroxide ion per molecule, $[OH^-]$ = molar concentration of base × degree of dissociation, and from (i), the degree of dissociation is 3.0×10^{-2}, so $[OH^-] = 1\times0.020\ \text{mol/L}\times3.0\times10^{-2} = \underline{6.0\times10^{-4}\ \text{mol/L}}$

(iii) Since pH = −log10[H+], first find the hydrogen ion concentration [H+].

From the ionic product of water $K_w = 1.0\times10^{-14}\ \text{mol}^2/\text{L}^2$, $[H^+][OH^-] = 1.0\times10^{-14}\ \text{mol}^2/\text{L}^2$

Therefore,

$$[H^+] = \frac{1.0\times10^{-14}\ \text{mol}^2/\text{L}^2}{[OH^-]} = \frac{1.0\times10^{-14}\ \text{mol}^2/\text{L}^2}{6.0\times10^{-4}\ \text{mol/L}} = \frac{1.0}{\underline{6.0}}\times10^{-10}\ \text{mol/L}$$

Therefore, the required pH is $\text{pH} = -\log_{10}[H^+]$

$$= -\log_{10}\left(\frac{1.0}{6.0}\times10^{-10}\right)$$

$$= -\left\{\log_{10}\left(\frac{1.0}{6.0}\right)+\log_{10}10^{-10}\right\}$$

$$= -(\log_{10}6.0^{-1}+\log_{10}10^{-10})$$

$$= -(-\log_{10}6.0+\log_{10}10^{-10})$$

$$= \log_{10}6.0-\log_{10}10^{-10}$$

$$= \log_{10}(2.0\times3.0)-\log_{10}10^{-10}$$

$$= \log_{10}2.0+\log_{10}3.0-\log_{10}10^{-10}$$

$= 0.30+0.48-(-10) = 10.78 \approx 10.8$ 10.8

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Data Interpretation Activity

Substance	Initial Temp (°C)	Electrical Conductivity
HCl	High	Very High
CH_3COOH	High	Low
Glucose	High	None

• Think Like a Chemist:.

1. Which substance is a strong electrolyte? .....

2. Which is a weak electrolyte?.....

3. Which is a non-electrolyte? .....

4. What evidence supports your classification? .....

Try

Choose the correct answer:

1. A strong electrolyte is best described as:

A. Partially ionized

B. Fully ionized in solution

C. Insoluble in water

D. Non-conducting

Answer: _____

2. Which substance is a weak electrolyte?

A. NaCl B. HCl

C. CH_3COOH D. Glucose

Answer: _____

Answer the following questions

3. Assume Kw = 1.0×10^{-14} mol^2/L^2, and calculate the pH to one decimal place. ($\log_{10}$ 2.0 = 0.3, $\log_{10}$ 5.0 = 0.7)

(a) Calculate the pH of 0.020 mol/L hydrochloric acid (degree of dissociation 1.0).

(b) Calculate the pH of a 0.050 mol/L aqueous acetic acid solution (degree of dissociation 0.050).

(c) Calculate the pH of a 0.025 mol/L aqueous barium hydroxide solution (degree of dissociation 1.0).

(d) Calculate the pH of 0.050 mol/L aqueous ammonia (degree of dissociation 0.020).

Answer: _____

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Exercise

1. Calculate the pH of the following aqueous solutions at 25°C to one decimal place. Assume the ionic product of water is $K_w = 1.0\times10^{-14}\ mol^2/L^2$. ($\log_{10}1.5 = 0.18$, $\log_{10}2.0 = 0.30$)

(a) 0.0050 mol/L sulfuric acid

Answer: _____

(b) 0.20 mol/L aqueous acetic acid solution (degree of dissociation 0.016)

Answer: _____

(c) 0.10 mol/L aqueous sodium hydroxide solution

Answer: _____

(d) 0.10 mol/L aqueous ammonia (degree of dissociation 1.5×10^{-2})

Answer: _____

2. In aqueous ammonia, the following dissociation equilibrium is established.

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

Assuming the dissociation constant of ammonia K_b is 1.8×10^{-5} mol/L, the ionic product of water K_w is $1.0\times10^{-14}\ mol^2/L^2$, and the degree of dissociation of ammonia is much smaller than 1, answer the following questions.

(a) Express the degree of dissociation α of ammonia in c [mol/L] aqueous ammonia using c and K_b.

Answer: _____

(b) Calculate the hydroxide ion concentration [OH^-] in 2.0 mol/L aqueous ammonia to two significant figures.

Answer: _____

(c) Calculate the pH of the aqueous ammonia in (b) to one decimal place. Assume $\log_{10}2 = 0.30$ and $\log_{10}3 = 0.48$.

Answer: _____

Challenge Your Thinking

A chemist compares two solutions:

- 0.1 M HCl
- 0.1 M CH_3COOH

Both are acids, but only one conducts strongly.

- Is conductivity determined by concentration alone? .....
- What role does ionization play? .....
- Can weak acids become strong conductors? Under what condition? .....
- Explain using equilibrium reasoning. .....

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Lesson 2-12 — Salt and Aqueous Solution

✨ Engaging Introduction

When you add hydrochloric acid to a solution of sodium acetate, at first glance nothing dramatic seems to happen. However, at the molecular level a hidden competition begins: ions collide, react, and shift equilibrium positions continuously.

In another case, adding sodium hydroxide to an ammonium salt produces a noticeable smell of ammonia gas — evidence that a weak base has been released from its salt form.

In this lesson, we will explore how equilibrium decides which acid or base survives in solution and how salts control the acidity or basicity of water.

❓ Guiding question: How does ionization equilibrium determine whether a weak acid or weak base is displaced in aqueous solution?

🔭 Exploration

Consider the following reactions:

• $CH_3COONa + HCl \rightarrow ?$

• $NH_4Cl + NaOH \rightarrow ?$

Without studying the lesson:

• What do you expect to form when a strong acid reacts with a salt of a weak acid?

.....

• What do you expect to form when a strong base reacts with a salt of a weak base?

.....

• Why do some salts produce acidic or basic solutions in water?

.....

📌 Point!

1. Displacement of weak acids and weak bases

(a) Displacement of weak acids: When a strong acid is added to a salt of a weak acid, a salt of the strong acid and a weak acid are formed.

Example: $\underset{\text{Salt of weak acid}}{CH_3COONa} + \underset{\text{strong acid}}{HCl} \longrightarrow \underset{\text{Salt of strong acid}}{NaCl} + \underset{\text{Weak acid}}{CH_3COOH}$

(b) Displacement of weak bases: When a strong base is added to a salt of a weak base, a salt of the strong base and a weak base are formed.

Example: $\underset{\text{Salt of weak base}}{NH_4Cl} + \underset{\text{Strong base}}{NaOH} \longrightarrow \underset{\text{Salt of strong base}}{NaCl} + \underset{\text{Weak base}}{NH_3} + \underset{\text{Water}}{H_2O}$

Structure of Science

Key Fact :

Strong acids and bases can displace weak acids and weak bases from their salts. • Buffer solutions resist changes in pH due to equilibrium control of ions.

Key Concepts:

.Ionization equilibrium
· Acid–base reaction
· Salt hydrolysis
· Displacement reaction
· Weak acid
· Weak base
· Strong acid
· Strong base
· Buffer solution
· Conjugate acid–base pair
· pH stability

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2. Salts and aqueous solutions

(a) Classification of salts

(i) Normal salt: A salt in which neither the H of the acid nor the OH of the base remains in the chemical formula. **Example:** Sodium carbonate Na_2CO_3

(ii) Acid salt: A salt in which the H of the acid remains. **Example:** Sodium hydrogen carbonate $NaHCO_3$

(iii) Basic salt: A salt in which the OH of the base remains. **Example:** Calcium chloride hydroxide CaCl(OH)

(b) Aqueous solutions of normal salts

Generally, the relationship between the composition of a normal salt and the property of its aqueous solution is as follows.

(i) Weak acid + Strong base ⟶ Basic

(ii) Strong acid + Weak base ⟶ Acid

(iii) Strong acid + Strong base ⟶ Neutral

(c) Aqueous solutions of acid salts

(i) An aqueous solution of sodium hydrogen carbonate $NaHCO_3$ is basic .

This is because HCO_3^- generated by ionisation reacts with H_2O to produce OH^-.

(ii) An aqueous solution of sodium hydrogen sulfate $NaHSO_4$ is acidic .

This is because HSO_4^- generated by ionisation further ionises to produce H^+.

3. Buffer action

(a) Buffering action : The ability to resist changes in pH even when a small amount of acid or base is added.

(b) Buffer solution : An aqueous solution that exhibits buffer action. Generally, a mixed aqueous solution of a weak acid or a weak base and its salt is used.

(c) Mechanism of buffer action (in the case of a mixed aqueous solution of acetic acid and sodium acetate)

Acetic acid is a weak acid, and sodium acetate is a salt of acetic acid.

In the aqueous solution, acetic acid and sodium acetate are ionised.

Ionisation of acetic acid: $CH_3COOH \rightleftharpoons CH_3COO^- + H^+$

Ionisation of sodium acetate: $CH_3COONa \longrightarrow CH_3COO^- + Na^+$

Misconception Alert

❌ Wrong idea:

„All salts produce neutral solutions."

✅ Correct:

The pH of a salt solution depends on the strengths of the acid and base from which the salt is formed.

❌ Wrong idea:

„A buffer solution prevents acids and bases from reacting."

✅ Correct:

A buffer solution allows reactions to occur but minimizes changes in pH through equilibrium shifts.

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(i) When H^+ is added, H^+ reacts with CH_3COO^- to form acetic acid molecules CH_3COOH.

$$CH_3COO^- + H^+ \longrightarrow CH_3COOH$$

⇒ $[H^+]$ hardly increases.

(ii) When OH^- is added, it reacts with acetic acid molecules to form water molecules H_2O.

$$CH_3COOH + OH^- \longrightarrow CH_3COO^- + H_2O$$

⇒ $[OH^-]$ hardly increases.

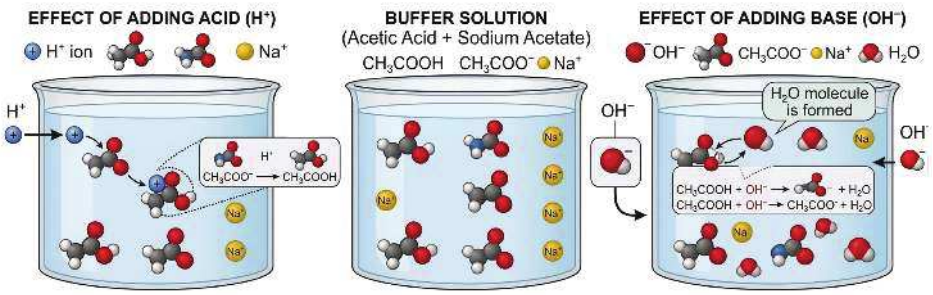

Figure 2.12.1 the three-panel buffer diagram

📦 Reference table — salts & buffers at a glance

Normal salt from…	Solution property
Strong acid + Strong base	Neutral
Strong acid + Weak base	Acidic
Weak acid + Strong base	Basic
Acid salt — $NaHCO_3$ / $NaHSO_4$	basic / acidic
Buffer (weak acid + its salt)	resists pH change
Add H^+ to buffer	$CH_3COO^- + H^+ \rightarrow CH_3COOH$
Add OH^- to buffer	$CH_3COOH + OH^- \rightarrow CH_3COO^- + H_2O$

Warm Up

Answer the following questions.

(a) Write the chemical equation for the reaction that occurs when hydrochloric acid is added to an aqueous sodium hydrogen carbonate solution.

(b) State whether the aqueous solutions of the following salts are acidic, basic, or neutral.

(i) NaCl (ii) $Ba(NO_3)_2$ (iii) NH_4Cl (iv) CH_3COONa

(c) Insert appropriate ionic equations into [A] and [B], and an appropriate word into (C) in the following text. Also, choose appropriate items for { D } and { E } from (i) to (v) below.

When a small amount of hydrochloric acid is added to a mixed aqueous solution containing equimolar amounts of acetic acid and sodium acetate, the reaction of

🌍 Be Global Citizen

Understanding buffer systems helps scientists:

- Develop safer medicines and intravenous solutions.
- Monitor and protect aquatic ecosystems from acidification.
- Improve food preservation technologies.
- Maintain stable conditions in industrial and biological processes.

Many sustainability and healthcare applications depend on controlling ionization equilibrium and buff.

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[A] occurs, and the hydrogen ion concentration is kept almost constant. Also, when a small amount of aqueous sodium hydroxide solution is added, the reaction of [B] occurs, and the hydroxide ion concentration is kept almost constant. Such an aqueous solution is called a (C), and a similar phenomenon occurs in a mixed aqueous solution containing equimolar amounts of the substances in { D } and { E }.

(i) NH_3 (ii) HCl (iii) NaCl (iv) NH_4Cl (v) CH_3COOH

Explanation

(a) Since sodium hydrogen carbonate is a salt of a weak acid and hydrochloric acid is a strong acid, sodium chloride, which is a salt of a strong acid, is formed, and the weak acid, carbonic acid, is displaced.

$NaHCO_3 + HCl \longrightarrow NaCl + H_2O + CO_2$

(b) (i) NaCl is a normal salt derived from the strong acid HCl and the strong base NaOH. Therefore, it is neutral .

(ii) $Ba(NO_3)_2$ is a normal salt derived from the strong acid HNO_3 and the strong base $Ba(OH)_2$. Therefore, it is neutral .

(iii) NH_4Cl is a normal salt derived from the strong acid HCl and the weak base NH_3. Therefore, it is acidic .

(iv) CH_3COONa is a normal salt derived from the weak acid CH_3COOH and the strong base NaOH.
Therefore, it is basic .

(c) A: $CH_3COO^- + H^+ \longrightarrow CH_3COOH$

B: $CH_3COOH + OH^- \longrightarrow CH_3COO^- + H_2O$

C: Buffer solution

D, E: A mixed aqueous solution of ammonia NH_3, which is a weak base, and ammonium chloride, which is a salt of ammonia, exhibits buffering action. (i), (iv) (in any order)

Data Interpretation Activity

Solution	Initial pH	Final pH after adding HCl
Distilled Water	7.0	3.0
CH_3COOH / CH_3COONa Buffer	4.8	4.7

Analyze Experimental Data

Think Like a Chemist

1. Which solution resisted the pH change most effectively? .....

2. What evidence supports your conclusion? .....

3. How did the equilibrium respond to the added acid? .....

4. Which solution demonstrates buffer action? .....

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Try

1. Write the balanced chemical equation for each of the following reactions.

(a) Add hydrochloric acid to an aqueous potassium acetate solution.
Answer: _____

(b) Add an aqueous calcium hydroxide solution to an aqueous ammonium chloride solution.
Answer: _____

2. State whether the aqueous solutions of the following salts are acidic, basic, or neutral.

(a) KNO_3 (b) $(NH_4)_2SO_4$ (c) Na_2CO_3 (d) $NaHSO_4$

3. Read the following text and answer the questions.

Acetic acid is a weak acid, slightly ionized in an aqueous solution, maintaining the following equilibrium.

$CH_3COOH \rightleftharpoons CH_3COO^- + H^+$ .....(i)

When sodium acetate is added to this aqueous solution, the salt completely dissociates, so the concentration of [A] increases, and according to Le Chatelier's principle, the equilibrium shifts to the (B). As a result, the concentration of H^+ decreases, resulting in an aqueous solution in which large amounts of [C] and [D] are present.

When a small amount of hydrochloric acid is added to this mixed aqueous solution, the chemical equilibrium of equation (i) shifts to the (E) side, and (I)[F] generated from hydrochloric acid combines with the large amount of CH_3COO^- present to become [G]. Therefore, the concentration of [H] in the mixed aqueous solution hardly changes.

Also, when a small amount of sodium hydroxide is added to the mixed aqueous solution, (II)[I] generated from sodium hydroxide reacts with CH_3COOH. Therefore, the concentration of [J] in the aqueous solution hardly changes. This function of keeping the pH of the solution almost constant is called (K).

(a) Insert appropriate chemical formulas into [ ], and appropriate words into ( ) in the text. The same item may be inserted multiple times.
Answer: _____

(b) Write the net ionic equation for the reaction in the underlined part I.
Answer: _____

(c) Write the net ionic equation for the reaction in the underlined part II.
Answer: _____

Think Critically

A scientist compares two solutions:

- Solution A: Acetic acid only
- Solution B: Acetic acid + sodium acetate

The same amount of hydrochloric acid is added to both solutions.

Evaluate the situation

1. Which solution will experience the smaller pH change? .....
2. Which ion is primarily responsible for resisting the increase in H^+ concentration?

.....

3. How does equilibrium shift after adding H^+ ions? .....
4. Why is the buffer solution considered a dynamic equilibrium system? .....

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Exercise

Choose the correct answer:

1. Which salt produces an acidic aqueous solution?

A. NaCl

B. $Ba(NO_3)_2$

C. NH_4Cl

D. CH_3COONa

Answer: _____

2. Which ionic equation explains the action of an acetate buffer when acid is added?

A. $CH_3COOH + OH^- \rightarrow CH_3COO^- + H_2O$

B. $CH_3COO^- + H^+ \rightarrow CH_3COOH$

C. $H^+ + OH^- \rightarrow H_2O$

D. $NH_4^+ + OH^- \rightarrow NH_3 + H_2O$

Answer: _____

Answer on the following questions

3. Write the balanced chemical equation for the reaction between the following substances.

(a) CH_3COONa, H_2SO_4

(b) NH_4Cl, NaOH

Answer: _____

4. Read the following text and answer the questions. (I) When sodium acetate is dissolved in water, it dissociates into acetate ions and sodium ions. A part of the acetate ions reacts with water molecules to produce hydroxide ions, so the aqueous solution is weakly (A).

(a) Insert an appropriate word into (A). Also write the net ionic equation for the reaction in the underlined part (I).

Answer: _____

(b) State whether each of the following aqueous solutions is acidic, basic, or neutral.

Answer: _____

(i) Equal volumes of 0.10 mol/L hydrochloric acid and 0.10 mol/L potassium hydroxide.

Answer: _____

(ii) Equal volumes of 0.10 mol/L acetic acid and 0.10 mol/L potassium hydroxide.

Answer: _____

(iii) Equal volumes of 0.10 mol/L hydrochloric acid and 0.10 mol/L aqueous ammonia.

Answer: _____

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Lesson 2-13 — Solubility Product

✨ Engaging Introduction

Two solutions—one clear and colorless, and the other yellow are mixed together in a laboratory. At first, nothing seems unusual. Suddenly, a brick-red solid appears and settles at the bottom of the beaker. Where did this solid come from?

At the microscopic level, dissolved ions are constantly moving through the solution. Sometimes they remain dissolved, while at other times they combine to form a precipitate. Chemists use the concept of solubility equilibrium and the solubility product constant (Ksp) to predict exactly when precipitation will occur.

In this lesson, we will explore how equilibrium controls the balance between dissolved ions and solid substances and how scientists use Ksp to predict chemical changes in natural and industrial systems.

❓ **Guiding question:** How can chemists predict whether dissolved ions will remain in solution or form a precipitate?

🔭 Predict what happens

A solution containing Ag^+ ions is mixed with a solution containing CrO_4^{2-} ions.

Without studying the lesson:

• Will the ions remain dissolved?

.....

• Could a solid form even though both solutions were initially clear?

.....

• What factors might determine whether precipitation occurs?

.....

Record your ideas and revisit them after studying solubility equilibrium..

📌 **Point!**

Solubility product

(a) Solubility equilibrium : A state in a saturated solution where the rate of dissolution equals the rate of precipitation, and macroscopically no net change is observed.

(b) Solubility product : The product of the concentrations of the dissolved ions at solubility equilibrium. It is denoted by the symbol K_{sp} and remains constant as long as the temperature does not change.

(c) Expression for Solubility Product

When a sparingly soluble salt A_aB_b consisting of A^{m+} and B^{n-} is in the following equilibrium,

⭐ Structure of Science

Key Fact :

Solubility equilibrium exists when the rate of dissolution equals the rate of precipitation.

• The solubility product constant (Ksp) depends only on temperature.

Key Concepts:

Solubility equilibrium
· Solubility product (Ksp)
· Saturated solution
· Dynamic equilibrium
· Dissolution
· Precipitation
· Ion product
· Ionic concentration
· Sparingly soluble salt.

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$A_aB_b \rightleftharpoons aA^{m+} + bB^{n-}$ (where $am = bn$)

the solubility product K_{sp} is expressed as follows.

$K_{sp} = [A^{m+}]^a[B^{n-}]^b$

Example: For silver chromate Ag_2CrO_4 , when the solubility equilibrium

$Ag_2CrO_{4(s)} \rightleftharpoons 2Ag^+ + CrO_4^{2-}$ is established,

Solubility product K_{sp} = $[Ag^+]^2[CrO_4^{2-}]$

(d) Solubility Product and Precipitation

Whether precipitation occurs in an aqueous solution is considered by comparing the product of the molar concentrations of ions with the solubility product.

Example: In the case of silver chromate Ag_2CrO_4

When $[Ag^+]^2[CrO_4^{2-}] \leq K_{sp}$, precipitation does not occur.

When the equality holds, a dissolution equilibrium is established.

When $[Ag^+]^2[CrO_4^{2-}] > K_{sp}$, precipitation occurs.

Warm Up

Hydrogen sulfide H_2S was passed through an aqueous solution containing 1.0×10^{-4} mol/L of lead(II) ions Pb^{2+} resulting in a sulfide ion concentration of 1.0×10^{-20} mol/L. Answer the following questions.

(a) Write the ionic equation at solubility equilibrium.

(b) Express the solubility product K_{sp}.

(c) Does precipitation of lead(II) sulfide PbS occur? Assume the solubility product of PbS is $K_{sp} = 1.0\times10^{-28}$ mol^2/L^2.

Explanation

(a) Hydrogen sulfide ionises to produce H^+ and S^{2-}. In the aqueous solution, Pb^{2+} and S^{2-} react to form PbS.

$PbS(s) \rightleftharpoons Pb^{2+} + S^{2-}$

(b) From **(a)**, since all the coefficients of the chemical equation are 1, $K_{sp} = [Pb^{2+}][S^{2-}]$

(c) Compare the product of the molar concentrations of ions, which is expressed by the same formula as K_{sp} , with K_{sp} .

Assuming precipitation of PbS does not occur, from

$[Pb^{2+}] = 1.0\times10^{-4}$ mol/L and $[S^{2-}] = 1.0\times10^{-20}$ mol/L,

$[Pb^{2+}][S^{2-}] = 1.0\times10^{-4}$ mol/L$\times1.0\times10^{-20}$ mol/L $= 1.0\times10^{-24}$ mol^2/L^2

Since $K_{sp} = 1.0\times10^{-28}$ mol^2/L^2 , $[Pb^{2+}][S^{2-}] > K_{sp}$

Therefore, precipitation occurs.

Misconception Alert

❌ Wrong idea:

"If a solid is visible in a solution, equilibrium has stopped."

✅ Correct:

Equilibrium continues because dissolution and precipitation occur simultaneously at equal rates.

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Data Interpretation Activity

Analyze Experimental Data

Solution	$[Ag^+]$ (mol/L)	$[CrO_4^{2-}]$ (mol/L)	Ion Product
A	1.0×10^{-4}	1.0×10^{-4}	1.0×10^{-12}
B	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-9}

Assume:

Ksp (Ag_2CrO_4) = 1.0×10^{-11}

Think Like a Chemist

1. In which solution is precipitation more likely? .....

2. Which solution has an ion product greater than Ksp? .....

3. What evidence supports your conclusion? .....

4. What happens when the ion product exceeds Ksp? .....

Try

In an aqueous solution where the molar concentration of magnesium ions (Mg^{2+}) is 1.0×10^{-3} mol/L, precipitation of magnesium hydroxide $Mg(OH)_2$ begins to form when the molar concentration of hydroxide ions (OH^-) exceeds x [mol/L]. Assume the solubility product of $Mg(OH)_2$ is 1.0×10^{-11} $[mol/L]^3$. Answer the following questions.

(a) Write the ionic equation for the reaction when precipitation forms and solubility equilibrium is reached.

(b) Write the solubility product expression for K_{sp}.

(c) Determine the value of x to two significant figures.

Answer: _____

Think Critically

A factory releases wastewater containing Pb^{2+} ions into a treatment system.

A scientist proposes adding sulfide ions (S^{2-}) to remove lead ions as solid PbS.

Evaluate the proposal.

1. Why might PbS precipitation occur? .....

2. What role does Ksp play in this process? .....

3. How can precipitation reduce environmental pollution? .....

4. What evidence would confirm that Pb^{2+} ions have been removed? .....

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Exercise

The solubility of silver chloride at 25°C is 1.9 mg/L. Answer the following questions to two significant figures. (Na = 23, Cl = 35.5, Ag = 108)

(a) What is the molar concentration of Ag^+ in a saturated solution of silver chloride at 25°C [in mol/L]?

(b) Determine the solubility product of silver chloride at 25°C.

(c) When sodium chloride is added gradually to 100 mL of a 1.0×10^{-3} mol/L aqueous silver nitrate solution, what is the minimum mass in milligrams of sodium chloride that must be added to initiate the precipitation of silver chloride?

Answer: _____

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Unit question

Sustainable Energy Systems: Choosing the Best Technology for a Green City

A city plans to reduce its carbon emissions by replacing conventional energy systems with cleaner technologies. Engineers are evaluating three technologies:

1. Hydrogen Fuel Cells
2. Lead-Acid Batteries
3. Hydrogen Production by Electrolysis

The following data have been collected.

Data Set 1: Energy and Environmental Information

Technology	Main Chemical Process	ΔH per mole of reaction".	Main Product
Hydrogen Fuel Cell	$2H_2 + O_2 \rightarrow 2H_2O$	−571.6 kJ	Water
Lead-Acid Battery (Discharge)	$Pb + PbO_2 + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$	Releases energy	Water and $PbSO_4$
Water Electrolysis	$2H_2O \rightarrow 2H_2 + O_2$	+572	Hydrogen and Oxygen

Data Set 2: Electrical Charge Production

System	Moles of Electrons Transferred
System A	1.0 mol
System B	2.0 mol
System C	5.0 mol

.....

.....

Section A: Multiple-Choice Question

Which statement is best supported by the data?

A. Water electrolysis is exothermic because hydrogen is produced.

B. Fuel cells and electrolysis have identical energy changes because they are the same process.

C. Water electrolysis requires energy input, while fuel cells release energy.

D. Lead-acid batteries and fuel cells both consume water as a reactant.

Answer

.....

Justification

.....

Section B: Short Response

Define enthalpy change (ΔH) and explain the difference between an exothermic and an endothermic process using the data provided.

.....

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Section C: Structured Problem

Calculate and Explain

Using Data Set 2:

(a) Calculate the electrical charge produced by each system.

(b)Identify which system could produce the greatest amount of chemical change.

(c)Explain your reasoning using Faraday's Law.

……

Section D: Data-Response Analysis

A student makes the following claim:

"Hydrogen fuel cells should completely replace lead-acid batteries because they produce only water."

Evaluate this claim.

In your answer:

- discuss scientific advantages,
- discuss limitations,
- consider energy production, storage, and sustainability,
- use evidence from the case study.

……

Section E: Extended Essay

To what extent can electrochemical technologies contribute to a sustainable energy future?

In your response:

- Explain the role of redox reactions in electrochemical cells.

……

- Compare fuel cells, lead-acid batteries, and electrolysis.

……

- Analyze the relationship between energy changes (ΔH) and electrical energy production.

……

- Discuss the environmental and economic implications of each technology.

……

- Use scientific evidence to support your conclusions.

……

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MINISTRY OF EDUCATION AND TECHNICAL EDUCATION

وزارة التربية والتعليم والتعليم الفني

Chemistry

Egyptian Baccalaureate

2nd Year

Part Two

11

SPRIX

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Chemistry

Egyptian Baccalaureate

2nd Year

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has reviewed the pedagogical and assessment approaches underpinning this textbook.

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Ministry of Education and Technical Education

New Administrative Capital

Cairo, Egypt

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How to use this book

Every lesson follows a scientific learning journey:
Observe ▪ Question ▪ Investigate ▪ Explain ▪ Apply ▪ Evaluate

1 Guiding Question
Each lesson begins with a guiding question that focuses your thinking and helps you connect chemistry to real-world phenomena.

2 Engaging Introduction
A short scenario, phenomenon, or authentic context introduces the lesson and demonstrates why the topic matters in everyday life, technology, and society.

3 Point!
Key concepts, definitions, laws, principles, and scientific models are presented clearly and systematically.

4 Exploration
Investigate patterns, analyze evidence, identify relationships, and make predictions before formal explanations are introduced.

5 Warm Up
Questions and Examples that help you in applying knowledge and prepare for deeper learning.

6 Explanation
Step-by-step explanations demonstrate scientific reasoning, calculations, and problem-solving strategies.

7 Think Like a Chemist
Apply scientific thinking to justify conclusions, evaluate claims, and interpret experimental results.

8 Think as an Engineer
Use chemistry concepts to solve practical problems and make evidence-based decisions in technological and engineering contexts.

9 Life Application
Discover how chemistry influences sustainability, health, energy production, industry, transportation, and everyday life.

10 Structure of Science
Explore the scientific concepts, models, and principles that connect the lesson to broader scientific understanding.

11 Nature of Science
Examine how scientists collect evidence, design investigations, evaluate data, and build reliable explanations.

12 Misconceptions Alert
Identify frequent mistakes and misconceptions so that your understanding becomes more accurate and scientifically sound.

13 Key equations at a glance
Important formulas, symbols, and relationships are summarized for quick reference.

14 Try
Practice your learning
Apply new concepts through guided questions and structured exercises.

15 Exercise
Strengthen your understanding through increasingly challenging questions that require reasoning, calculations, and analysis.

16 Challenge Your Thinking
Tackle higher-order questions that require evaluation, synthesis, problem-solving, and scientific argumentation.

17 Relect and grow
Revisit key concepts from current and previous lessons to strengthen long-term understanding and exam readiness.

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Your lessons and the EB syllabus

Second Part — every lesson mapped to its EB Chemistry topic

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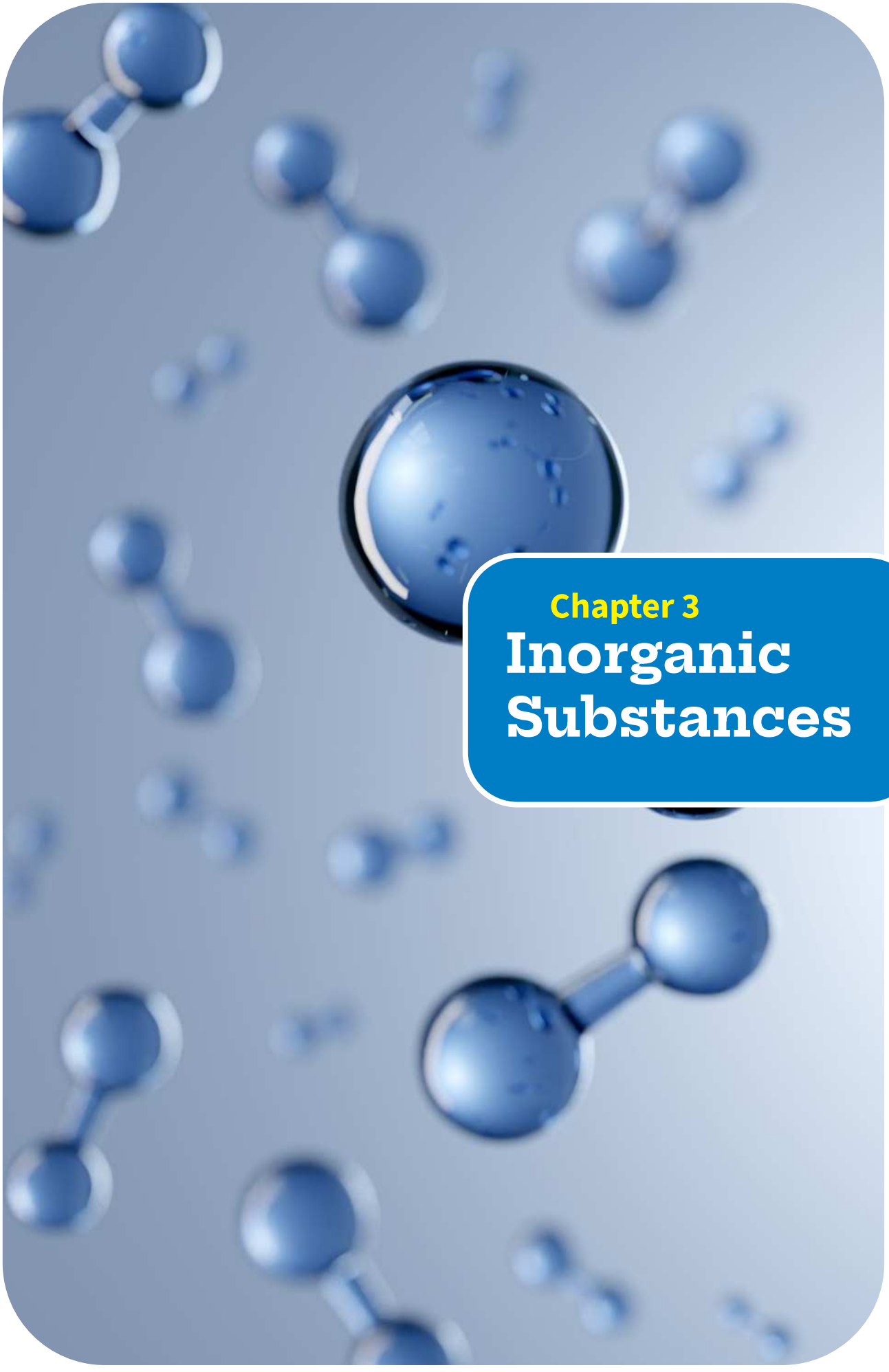

Chapter 3

Inorganic Substances

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Lesson 3-1 — Hydrogen and Noble Gases

Engaging Introduction

Hydrogen fuels spacecraft, powers fuel cells, and may become one of the world's cleanest energy sources. In contrast, noble gases such as helium and neon rarely react with other substances, yet they illuminate cities, preserve valuable materials, and enable advanced medical technologies.

In this lesson, you will investigate how the arrangement of electrons determines the chemical behavior of elements and why hydrogen and noble gases play such different—but equally important—roles in modern science and technology.

Guiding Question How does electron configuration determine whether an element is chemically reactive or chemically stable?

Exploration

A weather balloon filled with helium safely rises into the atmosphere.

Another balloon filled with hydrogen can produce a dramatic explosion when ignited.

Both gases are the lightest known substances.

Why do they behave so differently?

Without studying the lesson:

• Which gas would you choose for weather balloons? Why?…… ……

• Why is hydrogen widely used as a fuel while helium is not? ……

• What property makes noble gases almost completely unreactive?……

Point!

1.Hydrogen H_2

Properties of hydrogen

(i) A **colourless, odourless** gas, and the **lightest** of all gases.

(ii) **Poorly soluble** in water.

(iii) **Reduces** metal oxides at high temperatures.

$$CuO + H_2 \longrightarrow Cu + H_2O$$

figure 3.1.1 Reduction of Copper

Structure of Science

Key Fact :

• Hydrogen is the lightest element and acts as a reducing agent.

• Noble gases possess complete outer electron shells, making them highly stable.

• Electron arrangement explains many periodic trends and chemical properties.

Key Concepts:

• Hydrogen
• Reduction
• Oxidation
• Electron Configuration
• Valence Electrons
• Noble Gases
• Periodicity
• Chemical Stability
• Fuel Cells

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(iv) Used in **fuel cells** .

(v) Generated when hydrochloric acid or dilute sulfuric acid is added to **metals** such as iron or aluminium.

$$Fe + H_2SO_4 \longrightarrow FeSO_4 + H_2$$

Nature of Science

Observe

Hydrogen reacts with hot copper(II) oxide to produce copper metal.

$CuO + H_2 \rightarrow Cu + H_2O$

Infer

What role does hydrogen play in this reaction?

_____

Predict

Would hydrogen react similarly with other metal oxides?

Explain your reasoning.

_____

2. Noble Gases

(a) Noble gases

(i) He, Ne, Ar, Kr (Krypton), Xe (Xenon), Rn (Radon), and Og (Oganesson) in Group **18** of the periodic table.

(ii) The number of outermost shell electrons is **8** . Helium has **2** .

(iii) The number of valence electrons is **0** .

(b) Properties of noble gases

(i) The elements are **colourless, odourless** gases at room temperature.

(ii) Present in the air in trace amounts.

(iii) Melting points and boiling points are extremely **low** .

(iv) Hardly react with other atoms.

(v) Emit light when a voltage is applied.

Table 3-1-1 Properties of Noble Gas Elements

Element Name	Atomic Symbol	Atomic Electron Configuration (Shell) K	L	M	N	O	P	Boiling Point (°C)	Examples of Use
Helium	$_{2}He$	2						−269	Airships, Cryogenic Experiments
Neon	$_{10}Ne$	2	8					−246	Neon Signs
Argon	$_{18}Ar$	2	8	8				−186	Light Bulbs, Inert Gas for Welding
Krypton	$_{36}Kr$	2	8	18	8			−152	Light Bulbs, Inert Gas for Welding
Xenon	$_{54}Xe$	2	8	18	18	8		−107	Camera Strobes
Radon	$_{86}Rn$	2	8	18	32	18	8	−62	Medical Radiation Source

Chemistry in Everyday Life

Hydrogen: Fuel of the Future

Hydrogen-powered fuel cells produce electricity while releasing only water as a by-product.

Today, hydrogen technology is being developed for:

- Zero-emission vehicles
- Spacecraft propulsion
- Renewable energy storage
- Sustainable transportation

Misconception Alert

❌ Wrong idea:

„Noble gases never react under any circumstances."

✅ Correct:

Most noble gases are extremely unreactive, but heavier noble gases such as xenon can form compounds under special conditions.

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Warm Up

Answer the following questions.

(a) Choose one incorrect statement from the following descriptions about hydrogen and answer with its letter.

A. Hydrogen is the lightest of all gases and is poorly soluble in water.

B. Hydrogen is generated when dilute sulfuric acid is added to zinc.

C. Hydrogen acts as an oxidising agent and reacts with heated copper to produce copper(II) oxide.

(b) Choose one incorrect statement from the following descriptions about noble gases and answer with its letter.

A. The melting and boiling points of noble gases are low.

B. Some noble gases have a number of valence electrons that is not 0.

C. All Group 18 elements are noble gases.

Explanation

(a) Hydrogen acts as a reducing agent at high temperatures. Therefore, C.

(b) All noble gases have 0 valence electrons. Therefore, B.

Data Interpretation Activity

Gas	Relative Reactivity	Common Application
Hydrogen	High	Fuel cells
Helium	Very Low	Weather balloons
Neon	Very Low	Neon signs
Argon	Very Low	Welding

Think Like a Chemist

Which gas is most chemically reactive?

……

Which gases are suitable for protecting materials from oxidation?

……

What evidence supports your conclusion?

……

How does electron configuration explain these differences?

……

Try

1. Indicate whether the following statements are True or False.

(a) Hydrogen is the lightest of all gases and is highly soluble in water.

(b) Hydrogen acts as an oxidising agent and reacts with heated copper(II) oxide to produce copper.

(c) Hydrogen is used in fuel cells together with oxygen.

2. Indicate whether the following statements are True or False.

(a) Many noble gases are highly combustible.

Be Global Citizen

Noble gases contribute to sustainable technologies by:

- Improving energy-efficient lighting
- Supporting medical imaging and radiation therapy
- Advancing space exploration

Understanding the chemistry of inert gases helps scientists develop safer industrial processes and more sustainable technologies.

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(b) Elemental noble gases include both liquids and gases at room temperature and normal atmospheric pressure.

(c) All noble gas atoms have 8 electrons in their outermost shell.

(d) All noble gas atoms have 0 valence electrons.

Think Critically

A company wants to replace helium with hydrogen in commercial balloons because hydrogen is less expensive.

Evaluate this proposal.

• What are the scientific advantages?

……

• What are the potential safety risks?

……

• Which gas would you recommend?

……

Support your answer with scientific evidence.

……

Exercise

Choose the Correct Answer:

1. Which property makes helium suitable for filling weather balloons?

A. High density

B. High chemical reactivity

C. Low density and chemical stability

D. High solubility in water

……

2. Why can hydrogen reduce copper(II) oxide?

A. Hydrogen gains oxygen.

B. Hydrogen removes oxygen from copper oxide.

C. Copper loses electrons to hydrogen.

D. Hydrogen acts as an oxidizing agent.

……

3. Choose one incorrect statement from the following descriptions.

A. Hydrogen is the lightest of all gases and is highly soluble in water.

B. Hydrogen acts as a reducing agent and reacts with heated copper(II) oxide to produce copper.

C. Hydrogen is used in fuel cells together with oxygen.

D. Hydrogen is generated when dilute sulfuric acid is added to zinc.

4. Choose one correct statement from the following descriptions.

A. Noble gases are abundant in the air as compounds.

B. All noble gas atoms have 8 electrons in their outermost shell.

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C. All elemental noble gases are gases at room temperature and normal atmospheric pressure.

D. Many noble gases are highly combustible.

E. When a noble gas is kept at low pressure, it emits a light of a characteristic colour.

Challenge Your Thinking

A scientist claims:

"Since hydrogen is the lightest element, it should always be the safest gas for lifting balloons."

Evaluate the claim.

• Is the reasoning scientifically valid?

_____

• Which properties should be considered besides density?

_____

• Why is helium preferred in many real-world applications?

_____

Use scientific evidence to justify your answer.

_____

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Lesson 3-2 — Halogens and Their Compounds

Engaging Introduction

Imagine swimming in a pool on a hot summer day. The water looks clean and safe because it has been disinfected with chlorine compounds. In another laboratory, a forensic scientist adds a few drops of silver nitrate to an unknown solution and immediately identifies which halogen is present from the color of the precipitate.

Although halogens are among the most reactive non-metals, they play essential roles in public health, chemical analysis, medicine, and industry. Their behavior is governed by periodic trends, oxidation–reduction reactions, and electron transfer.

In this lesson, you will investigate why halogens differ in oxidising power, how chemists identify halide ions, and why chlorine compounds have become indispensable in modern society.

Guiding Question Why do halogens show different chemical reactivities even though they belong to the same group in the periodic table?

Exploration

Two swimming pools receive the same amount of disinfectant.

One remains crystal clear.

The other quickly becomes cloudy and contaminated.

Without studying the lesson:

• What chemical properties make chlorine an effective disinfectant?

……

• Why are chlorine compounds used instead of pure chlorine gas in many applications?

……

• How might chemists verify whether chloride ions are present in the pool water?

……

Point!

1. Halogens

(a) Halogens: F, Cl, Br, I, and At (Astatine) in Group 17 of the periodic table.

(b) Elemental halogens

All elemental halogens are diatomic molecules and act as oxidising agents.

The strength of the oxidising power is $F_2 > Cl_2 > Br_2 > I_2$.

Structure of Science

Key Fact :

• All halogens exist as diatomic molecules.

• Halogens are strong oxidising agents.

• Oxidising power decreases down Group 17.

• Chlorine compounds are widely used as disinfectants because of their oxidising ability.

Key Concepts:

Halogens

• Oxidation

• Reduction

• Oxidising Agent

• Hydrogen Halides

• Electronegativity

• Hydrogen Bonding

• Halide Ions

• Precipitation

• Oxoacids

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〈Properties of chlorine Cl_2〉

- Has a **pungent odour** .
- A toxic, **yellow-green** gas at room temperature.
- **Heavier** than air, and **soluble** in water.

Capture by downward delivery.

- Generated by adding concentrated hydrochloric acid to manganese(IV) oxide MnO_2 and heating. The chemical equation is:

$$MnO_2 + 4HCl \longrightarrow MnCl_2 + 2H_2O + Cl_2$$

(Figure 3-2-1 on the right)

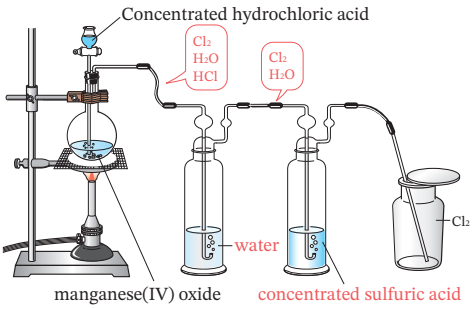

Figure 3-2-1 Generating of Chlorine

The generated gas is mixed with substances other than chlorine.

1. **Hydrogen chloride** is removed by **water** .
2. **Water** is removed by **concentrated sulfuric acid** .

Nature of Science

Observe

Chlorine gas has a yellow-green color and a pungent odor.
It is denser than air and dissolves in water.

Explain

Why is chlorine collected by downward delivery instead of over water?

.....

Predict

What would happen if chlorine were collected over water?

.....

2. Compounds of Halogens

(a) Hydrogen Halides

Hydrogen halides are compounds formed between halogen elements and hydrogen. They are all colourless, toxic gases with a pungent odour.

(i) Hydrogen Fluoride (HF)

Its aqueous solution is called **Hydrofluoric Acid** and is the only **weak acid** among the hydrogen halides.

[Explanation for being a weak acid]

Fluorine (F) has a very high **electronegativity** (tendency to strongly attract electrons). As a result, HF molecules **associate** through **hydrogen bonding**. This association makes it difficult for the molecule to release hydrogen ions (H^+) in water, resulting in weak acidity.

(ii) Hydrogen Chloride (HCl)

Its aqueous solution is known as **Hydrochloric Acid** and is a **strong acid** . When it reacts with ammonia (NH_3), it produces a **white smoke** consisting of fine crystals of ammonium chloride (NH_4Cl).

$$HCl + NH_3 \longrightarrow NH_4Cl$$

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Scientific Investigation

A scientist receives three unknown solutions that may contain chloride, bromide, or iodide ions.

Plan an investigation using silver nitrate solution.

Students should identify:

Independent variable

……

Dependent variable

……

Controlled variables

……

Evidence to collect

……

(b) Identification of Halide Ions

When aqueous silver nitrate solution ($AgNO_3$) is added to an unknown aqueous solution, precipitates of different colours are formed depending on the halogen present. This reaction can be used to identify the type of halide ion.

Table 3-2-1: Solubility of Silver Halides in Water

Precipitate	Colour	Solubility in Water
AgF	Soluble (No precipitate formed)	Soluble
AgCl	White	Insoluble (Precipitate)
AgBr	Pale Yellow	Insoluble (Precipitate)
AgI	Yellow	Insoluble (Precipitate)

(c)Oxoacids of Halogens and Their Salts

Acids in which an oxygen atom is bonded to a halogen atom are called **oxoacids**. A salt of a chlorine oxoacid, known as "bleaching powder," is widely used in everyday life.

(i) **Formation of Bleaching Powder**

When chlorine gas (Cl_2) is absorbed by calcium hydroxide (**slaked lime**), **bleaching powder** (**$CaCl(ClO)\cdot H_2O$**) is produced.

$Ca(OH)_2 + Cl_2 \longrightarrow CaCl(ClO)\cdot H_2O$

(ii) **[Mechanism] Principle of Bleaching and Disinfection**

The hypochlorite ion (ClO^-), a component of bleaching powder, possesses extremely strong **oxidising power**. This oxidising power is used to destroy the molecular structure of pigments to remove colour (**bleaching**) and to destroy and kill bacterial cells (**disinfection**).

Note: In recent years, "high-test hypochlorite" ($Ca(ClO)_2\cdot 2H_2O$), which has a higher concentration of active ingredients, is also widely used for disinfecting swimming pools and other applications.

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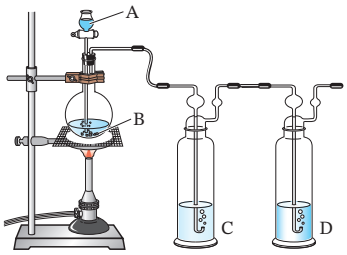
Warm Up

Chlorine was generated using the apparatus shown in the figure on the right. Answer the following questions.



(a) Choose the substances A to D in the figure from the following respectively.
(i) Concentrated sulfuric acid (ii) Concentrated hydrochloric acid
(iii) Water (iv) Manganese(IV) oxide

(b) Choose the substances removed at C and D from the following respectively.
(i) Water (ii) Oxygen (iii) Hydrogen chloride

(c) Choose the appropriate collection method for chlorine from the following.
(i) Upward delivery (ii) Downward delivery (iii) Collection over water

Chemistry and Society
Understanding halogen chemistry allows scientists to:
- Produce safe drinking water
- Develop effective disinfectants
- Manufacture pharmaceuticals
- Improve forensic chemical analysis
- Monitor environmental water quality

Explanation

(a) Add concentrated hydrochloric acid to solid manganese(IV) oxide. For the generated gas, first, hydrogen chloride is removed by water, and then water is removed by concentrated sulfuric acid.

If water is placed after, water vapour will be mixed into the gas again after the water is removed by concentrated sulfuric acid.

A: (ii) B: (iv) C: (iii) D: (i)

(b) C: (iii) D: (i)

(c) Because chlorine is soluble in water and heavier than air, it is collected by downward delivery. (ii)

Try

Choose the correct answer.

1. Which hydrogen halide is classified as a weak acid?

A. HCl
B. HBr
C. HI
D. HF

.....

2. Why is chlorine collected by downward delivery?

A. It is lighter than air.
B. It reacts with oxygen.
C. It is denser than air and soluble in water.
D. It is insoluble in water.

.....

3. Choose the two statements from A to D below that contain errors, and answer with their letters.

A All elemental halogens are diatomic molecules.
B The strength of the oxidising power of halogens is in the order of I2>Br2>Cl2>F2.
C Hydrogen fluoride is a strong acid and has the property of dissolving glass.

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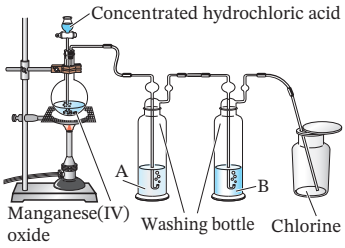
D Chlorine is a yellow-green gas and has a pungent odour.

4- The figure on the right is an apparatus for obtaining dry chlorine. Fill in the blanks ( ) in the following text with the appropriate words. Answer (vi) with a chemical formula.



In this experiment, chlorine is generated by the reaction:

$MnO_2 + 4HCl \longrightarrow MnCl_2 + 2H_2O + Cl_2$.

After that, (i) is placed in washing bottle A to absorb (ii) in the gas. (iii) is placed in washing bottle B to absorb (iv) in the gas. This yields dry chlorine gas.

Chlorine has strong oxidising power, and when chlorine is passed through an aqueous potassium iodide solution, (v) is liberated in the aqueous solution. Expressing this with a reaction equation:

$2KI + Cl_2 \longrightarrow 2KCl +$ (vi)

Evaluate the Evidence

A newspaper article states:

"Because chlorine kills bacteria, increasing the chlorine concentration always makes water safer."

Evaluate this statement.

• Is the claim scientifically accurate?

……

• What evidence should be considered?

……

• Can excessive chlorine create health or environmental problems?

……

Use scientific reasoning to justify your answer.

……

Exercise

1. Answer the following questions.

(a) For elemental halogens, does the oxidising power increase or decrease as the atomic number decreases?

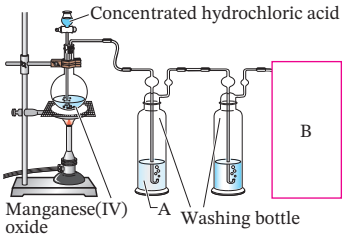
(b) Among the following hydrogen halides, choose all strong acids and answer with their letters.

(A) HF **(B)** HCl **(C)** HBr **(D)** HI

(c) Among the following hydrogen halides, choose the one that dissolves glass and answer with its letter.

(A) HF **(B)** HCl **(C)** HBr **(D)** HI

2. The figure below is an apparatus for obtaining dry chlorine, where chlorine was generated using concentrated hydrochloric acid and manganese(IV) oxide. Answer the following questions regarding this.



(a) Write a chemical equation for the generation of chlorine in this experiment.

(b) Write the name of the substance placed in washing bottle A and the name of the substance removed by it, respectively.

(c) State the collection method at the gas collection part B.

(d) State the colour and odour of the generated chlorine.

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Lesson 3-3 — Oxygen, Sulfur and Their Compounds

Engaging Introduction

Every day, oxygen keeps us alive, purifies drinking water, and supports countless industrial processes. Meanwhile, sulfur compounds are found in car batteries, fertilizers, food preservation, and even the acid rain that affects our environment. Although these substances all contain oxygen or sulfur, they behave very differently because of their molecular structures and chemical properties.

In this lesson, you will investigate how differences in molecular structure lead to very different chemical behaviors and how these properties are applied to solve real-world challenges.

Guiding Question How does the structure of oxygen and sulfur compounds determine their chemical properties and their applications in everyday life?

Exploration

Think about these everyday situations:

You breathe oxygen every second to stay alive.

A candle keeps burning only when oxygen is present.

Some bottled drinking water is purified using ozone before it reaches your home.

Without studying this lesson, discuss the following questions.

Observation: What do all three situations have in common?.....

Prediction: Do you think oxygen (O_2) and ozone (O_3) behave in exactly the same way? Why? .....

Inquiry: Why is ordinary oxygen safe to breathe, while ozone is used only in small amounts for sterilizing water? ……..

Point!

1. Oxygen O_2

(a) Properties of oxygen

- A colourless, odourless gas.
- Poorly soluble in water.

Collected by collection over water.

(b) Generation method of oxygen

Hydrogen peroxide is decomposed using manganese(IV) oxide MnO_2 as a catalyst.

Chemical equation: $2H_2O_2 \xrightarrow{MnO_2} 2H_2O + O_2$

(c) Ozone O_3: An allotrope of oxygen.

(i) Properties

- A toxic gas with a pale blue colour and a characteristic odour.
- Acts as a strong oxidising agent and is used for sterilising drinking water and bleaching fabrics.

Structure of Science

Key fact :

Oxygen and ozone are allotropes with different molecular structures.

- Ozone is a stronger oxidising agent than oxygen.
- Sulfuric acid exhibits different chemical properties depending on its concentration.

Key concepts:

Allotropy
- Catalyst
- Oxidation
- Reduction
- Sulfuric Acid
- Dehydration
- Oxidising Agent
- Hygroscopic Substance

- Atmospheric pressure
- Gas pressure

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(ii) Generation method

• Subject oxygen to silent electrical discharge.

$$3O_2 \longrightarrow 2O_3$$

• Expose oxygen to **ultraviolet rays** .

Think Like a Scientist

Oxygen and ozone are made from the same element.
Yet one supports life while the other can damage lung tissue.
Explain.
• Why do these substances have different properties?.....
• What evidence supports your explanation?.....

2. Compounds of Sulfur S

(a) Hydrogen sulfide **H_2S**

• Generated by adding dilute sulfuric acid or dilute hydrochloric acid to iron(II) sulfide.

• Acts as a strong **reducing agent** .

(b) Sulfur dioxide **SO_2**

• Obtained by burning **sulfur** .

• Acts as a reducing agent, but acts as an oxidising agent against strong reducing agents such as hydrogen sulfide.

Evidence-Based Reasoning

A student spills concentrated sulfuric acid on a piece of paper.
After a few minutes the paper becomes black.
Claim: Sulfuric acid removed water from the paper.
Evidence.....
Reasoning .....

(c) Concentrated sulfuric acid and dilute sulfuric acid **H_2SO_4**

(i) Manufacturing process of sulfuric acid: Produced by the **Contact process** .

〈Contact process〉

❶ Sulfur dioxide SO_2 is oxidised using vanadium(V) oxide V_2O_5 as a catalyst to produce **sulfur trioxide SO_3** .

❷ SO_3 is absorbed into concentrated sulfuric acid and reacted with the water in it.

❶ $S + O_2 \longrightarrow SO_2$
$2SO_2 + O_2 \xrightarrow{V_2O_5} 2SO_3$
❷ $SO_3 + H_2O \longrightarrow H_2SO_4$

(ii) Properties of concentrated sulfuric acid

• It is **non-volatile** , and when reacted with a salt of a volatile acid, the volatile acid is liberated.

Example: $NaCl + H_2SO_4 \longrightarrow NaHSO_4 + HCl$
(Salt of a volatile acid; Volatile acid)

• Highly **hygroscopic** , and is used as a desiccant.

• Has a **dehydrating** effect.

It removes hydrogen atoms and oxygen atoms from organic compounds in the same proportion as water (H_2O).

Example: When concentrated sulfuric acid is added to formic acid HCOOH, carbon monoxide CO is generated.

• Hot concentrated sulfuric acid acts as a strong **oxidising agent** and dissolves

Misconception Alert

❌ Wrong idea:

„Oxygen and ozone have identical chemical properties because they are both made of oxygen atoms."

✅ Correct:

Oxygen and ozone are allotropes with different molecular structures, giving them different physical and chemical properties.

Chemistry in Industry

Sulfur compounds are essential in manufacturing Fertilizers, Car batteries, Industrial chemicals, Paper, and pharmaceuticals

Among them, sulfuric acid is often called the world's most important industrial chemical because the amount produced by a country is often used as an indicator of industrial development.

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metals such as copper and silver.

$$Cu + 2H_2SO_4 \longrightarrow CuSO_4 + 2H_2O + SO_2$$

(iii) Properties of dilute sulfuric acid

- It is a **strong acid** .
- Reacts with metals that are more reactive than hydrogen, such as zinc and iron, to generate hydrogen.

$$Zn + H_2SO_4 \longrightarrow ZnSO_4 + H_2$$

Warm Up

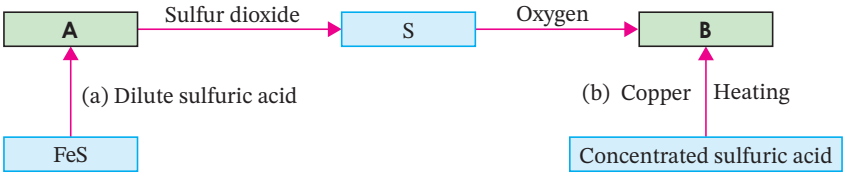
Answer the following questions.

(a) Answer the following questions about the generation of oxygen.

(i) Write the balanced chemical equation for the decomposition of hydrogen peroxide catalyzed by manganese(IV) oxide.

(ii) State the most appropriate collection method for oxygen.

(b) The following diagram shows sulfur and its compounds. Answer the questions below.



(i) Write the balanced chemical equation for the reaction occurring in step (b).

(ii) What properties of dilute sulfuric acid or concentrated sulfuric acid are utilized in the changes (a) and (b)? Choose from the following.

A. Non-volatile B. Dehydrating effect C. Strong acidity D. Oxidising property

(iii) When 1.0 kg of sulfur is completely converted into sulfuric acid, calculate the mass (in kg) of 98% concentrated sulfuric acid that can be produced. Express your answer to two significant figures. (H = 1.0, O = 16, S = 32)

Explanation

(a) (i) $2H_2O_2 \longrightarrow 2H_2O + O_2$

(ii)Oxygen is poorly soluble in water. Gases that are poorly soluble in water are collected by collection over water. Answer: Collection over water.

(b)(i)First, substance B is formed by the reaction of sulfur and oxygen, so it must be sulfur dioxide (SO_2).
Therefore, the change in (b) is the reaction where sulfuric acid H_2SO_4 and copper react to produce SO_2.
The chemical equation is: $Cu + 2H_2SO_4 \longrightarrow CuSO_4 + 2H_2O + SO_2$

(ii) (a) When dilute sulfuric acid is added to iron(II) sulfide FeS, hydrogen sulfide H_2S is generated.
This is a reaction in which the weak acid H_2S is liberated due to the reaction of the strong acid H_2SO_4 with the salt of a weak acid FeS.

Sustainability Connection

Chemistry for a Sustainable Planet

Many technologies that improve our quality of life depend on oxygen and sulfur chemistry.

- Fertilizers that improve crop production.
- Batteries that store renewable energy.
- Cleaner factories that remove sulfur dioxide before it reaches the atmosphere.

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Therefore, C.

Also, dilute sulfuric acid does not have non-volatile properties, dehydrating effects, or oxidising effects.

(b) Hot concentrated sulfuric acid acts as a strong oxidising agent and reacts with metals to dissolve them, as in (i). D

(iii) The reactions to produce sulfuric acid from sulfur are as follows:

$$S + O_2 \longrightarrow SO_2$$
$$2SO_2 + O_2 \longrightarrow 2SO_3$$
$$SO_3 + H_2O \longrightarrow H_2SO_4$$

Therefore, 1 mol of sulfuric acid is produced from 1 mol of sulfur.

From sulfur S = 32, the amount of substance of 1.0 kg of sulfur is $\frac{1000}{32}$ mol, so the produced concentrated sulfuric acid is also $\frac{1000}{32}$ mol.

Letting the mass of 98% concentrated sulfuric acid H_2SO_4 be x [g], and since the molar mass of H_2SO_4 is 98:

$$\frac{1000}{32}\ \text{mol} = \frac{x\ [\text{g}] \times 0.98}{98\ \text{g/mol}}$$

$$x = 3.12 \times 10^3$$
$$\approx 3.1 \times 10^3\ \text{g}$$

Therefore, 3.1 kg.

Interpreting Experimental Data

Substance	Observation
Oxygen	Supports combustion
Ozone	Bleaches dyes
Concentrated H_2SO_4	Turns sugar black
Dilute H_2SO_4	Produces H_2 with Zn

Think Like a Chemist

Which substance acts mainly as a dehydrating agent?

……

Which acts as the strongest oxidising agent?

……

Which observations support your answer?

……

Which chemical property explains each application?

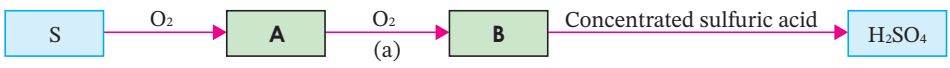
……

Try

1. Identify the appropriate terms for (i) and (ii) in the following passage.

When oxygen is subjected to a silent electrical discharge, (i) is produced. To generate (i), another method is to expose oxygen to (ii). (i) has bleaching and sterilizing effects.

2. Answer the following questions based on the diagram showing the reactions of sulfur and its compounds. (H = 1.0, O = 16, S = 32)



(i) Identify the chemical formulas for substances A and B.

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(ii) Write the name of the catalyst used in (a).

(iii) Name the industrial process used to manufacture concentrated sulfuric acid.

(iv) Assuming complete conversion, calculate the mass (in kg) of 98% concentrated sulfuric acid that can be produced from 9.6 kg of sulfur. Express your answer to two significant figures.

3.Match each of the following reactions **(a)** through **(e)** with the corresponding property of sulfuric acid (A through E) that is utilized.

(a) When zinc was added to dilute sulfuric acid, hydrogen was generated.

(b) When sodium chloride was added to concentrated sulfuric acid and heated, hydrogen chloride was generated.

(c) When carbon dioxide containing water vapour was passed through concentrated sulfuric acid, dry carbon dioxide was obtained.

(d) When copper was added to concentrated sulfuric acid and heated, sulfur dioxide was generated.

(e) When concentrated sulfuric acid was added to formic acid and heated, carbon monoxide was generated.

A Non-volatile **B** Dehydrating property **C** Hygroscopic property **D** Oxidising property **E** Strong acidity

Think Critically

A company claims: "Ozone should completely replace chlorine in every water-treatment system because it is a stronger oxidising agent."

Evaluate this claim.

- What scientific evidence supports the claim? .....
- What limitations should also be considered? .....
- Would ozone always be the better choice?

Support your answer with evidence. .....

Exercise

1. Which statement correctly explains why ozone is a better disinfectant than oxygen?

   A. Ozone has a lower molecular mass.

   B. Ozone is a stronger oxidising agent.

   C. Ozone is more soluble in water.

   D. Ozone is less reactive.

   .....

2. Which property of concentrated sulfuric acid allows it to dry gases?

   A. Strong acidity

   B. Hygroscopic nature

   C. Non-volatility

   D. Weak oxidation

   .....

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3. Answer the following questions.

(a) Write the balanced chemical equation for the decomposition of hydrogen peroxide catalyzed by manganese(IV) oxide.

(b) Identify the role of manganese(IV) oxide used in **(a)**.

(c) Identify the most appropriate collection method for oxygen gas.

(d) What is produced when oxygen is subjected to a silent electrical discharge?

4. Read the following text and answer the questions below.

Sulfur dioxide is synthesised by burning sulfur and serves as a raw material for sulfuric acid. Concentrated sulfuric acid is manufactured industrially by oxidising sulfur dioxide in the presence of a small amount of vanadium(V) oxide V_2O_5, and reacting the produced ( ) with water.

(a) Identify the substance that goes in the parentheses ( ).

(b) Name the industrial process described in the underlined part.

(c) Assuming complete conversion, calculate the mass (in kg) of 98% concentrated sulfuric acid that can be produced from 4.8 kg of sulfur. Express your answer to two significant figures. (H = 1.0, O = 16, S = 32)

5. Match each of the following reactions (i) through (iv) with the corresponding property of sulfuric acid (A through D) that is utilized.

(i) When concentrated sulfuric acid is added to sodium chloride and heated, hydrogen chloride is generated.

(ii) When concentrated sulfuric acid is added to sucrose $C_{12}H_{22}O_{11}$, it turns black.

(iii) When dilute sulfuric acid is added to zinc, hydrogen is generated.

(iv) When concentrated sulfuric acid is added to copper and heated, sulfur dioxide is generated.

A Non-volatility	B Oxidising property	C Dehydrating property	D Strong acidity

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Lesson 3-4 — Nitrogen, Phosphorus and Their Compounds

Engaging Introduction

Every day, billions of people depend on crops grown with fertilizers that contain nitrogen and phosphorus. Without these compounds, many plants would not grow fast enough to produce enough food for the world's population. Behind every bag of fertilizer is a remarkable achievement of chemistry: scientists learned how to convert nitrogen from the air into useful compounds that plants can absorb.

In this lesson, you will discover how chemists transform nitrogen from the atmosphere into ammonia and nitric acid, why phosphorus is essential for plant growth, and how these industrial processes have changed modern agriculture and society.

Guiding Question How do chemists convert abundant natural resources into compounds that support life, agriculture, and industry?

Exploration

Look at these everyday situations:

A farmer spreads fertilizer on crops.

Plants become greener and grow faster.

Although almost 78% of the air is nitrogen, plants cannot use most of it directly.

Observation: What do you notice about the relationship between air and plant growth?

……

Inference: Why do farmers still need fertilizers if the atmosphere already contains large amounts of nitrogen?

……

Prediction: How might chemists convert nitrogen gas into a form that plants can use?

……

Point!

1. Nitrogen N_2

(a) Nitrogen compounds

(i) Ammonia **NH_3**

- A **colourless** gas with a **pungent** odour. **Lighter** than air.
- **Easily soluble** in water, and the aqueous solution is **basic** (alkaline).

(ii) Nitric acid **HNO_3**

- Both concentrated and dilute nitric acid have strong **oxidising** power and dissolve metals such as copper and silver.

Structure of Science

Key fact :

- Nitrogen gas is abundant but chemically unreactive.
- Ammonia is the starting material for producing nitric acid and many fertilizers.
- Different allotropes of phosphorus have different physical and chemical properties.

Key concepts:

Nitrogen Fixation
- Catalyst
- Haber–Bosch Process
- Ostwald Process
- Fertilizers

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• Because it is easily decomposed by light or heat, it is stored in an amber bottle in a cool, dark place.

(iii) Nitric oxide (Nitrogen monoxide) **NO**

• Produced when dilute nitric acid reacts with copper.

$$3Cu + 8HNO_3 \longrightarrow 3Cu(NO_3)_2 + 4H_2O + 2NO$$

(iv) Nitrogen dioxide **NO_2**

• Produced when concentrated nitric acid reacts with copper.

$$Cu + 4HNO_3 \longrightarrow Cu(NO_3)_2 + 2H_2O + 2NO_2$$

(b) Industrial manufacturing processes of nitrogen compounds

(i) **Haber-Bosch process** : A method for manufacturing ammonia.

• Produced from nitrogen and hydrogen using **iron(II,III) oxide (triiron tetraoxide), Fe_3O_4** and others as a catalyst.

$$N_2 + 3H_2 \overset{Fe_3O_4}{\rightleftharpoons} 2NH_3$$

(ii) **Ostwald process** : A method for manufacturing nitric acid.

❶ Oxidise ammonia using **platinum Pt** and others as a catalyst to produce nitric oxide.

$$4NH_3 + 5O_2 \xrightarrow{Pt} 4NO + 6H_2O$$

❷ Oxidise nitric oxide to make nitrogen dioxide. $2NO + O_2 \longrightarrow 2NO_2$

❸ Absorb nitrogen dioxide in warm water to make nitric acid.

$$3NO_2 + H_2O \longrightarrow 2HNO_3 + NO$$

⇒ Expressing the overall reaction of ⍰ to ⍰ with a chemical equation:

$$NH_3 + 2O_2 \longrightarrow HNO_3 + H_2O$$

Think as an Engineer

Scientists wanted to produce ammonia efficiently on a large scale.
Instead of simply mixing nitrogen and hydrogen, they designed conditions that maximize production.
Investigation Question
Why are high pressure, suitable temperature, and catalysts used together during the Haber–Bosch process? ……
How might changing one of these conditions affect ammonia production?
……

2. Phosphorus P

(a) Allotropes of phosphorus

(i) White phosphorus (Yellow phosphorus)

• A **pale yellow** , highly toxic **solid** .

• Because it **spontaneously ignites** in air, it is stored in water.

(ii) Red phosphorus

• A **reddish-brown** powder with weak toxicity.

• Produced by heating white phosphorus in the absence of air.

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(b) Phosphorus compounds

(i) Tetraphosphorus decaoxide P_4O_{10}

- A **white** powder produced by burning white or red phosphorus.
- It is highly **deliquescent** (absorbs moisture from the air and dissolves).

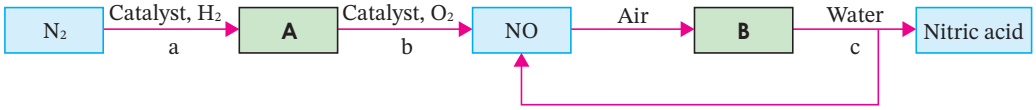
(ii) Phosphoric acid H_3PO_4

- Colourless crystals produced by dissolving tetraphosphorus decaoxide in water and heating.
- Its salts are used in fertilizers.

Warm Up

Answer the following questions.

(a) The following figure shows the process of industrial manufacturing of nitric acid. Answer the questions below.



(i) Identify the chemical formulas for substances A and B.

(ii) Write the names of the catalysts used in reactions a and b, respectively.

(iii) Write the balanced chemical equations for reactions b and c.

(b) Which of the following statements (A to D) about phosphorus is incorrect?

A. Phosphorus is an element belonging to the same group as nitrogen.

B. Elemental phosphorus burns in the air to become tetraphosphorus decaoxide.

C. Tetraphosphorus decaoxide is a white solid at room temperature.

D. Red phosphorus spontaneously ignites in the air.

Explanation

(a) (i) A: When nitrogen and hydrogen react, ammonia is produced.

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

B: Nitric oxide is quickly oxidised in the air to become nitrogen dioxide.

$$2NO + O_2 \longrightarrow 2NO_2$$

(ii)a: Iron(II, III) oxide

b: From part (i), A is NH_3. When producing nitric oxide from ammonia, platinum Pt or similar is used as a catalyst. Answer: Platinum.

(iii)b: $4NH_3 + 5O_2 \longrightarrow 4NO + 6H_2O$

c: From part (i), B is $3NO_2 + H_2O \longrightarrow 2HNO_3 + NO$

(b) Red phosphorus is a stable substance, and white phosphorus spontaneously ignites in the air. Therefore, D.

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Data Interpretation

Analyze Industrial Production

Compound	Main Use
NH_3	Fertilizers
HNO_3	Fertilizers, explosives
H_3PO_4	Fertilizers
P_4O_{10}	Drying agent

Think Like a Chemist

Which compound is produced directly from nitrogen gas?

……

Which compound is produced from ammonia?

……

Which compounds contribute directly to agriculture?

……

Why are catalysts essential in these industrial processes?

……

Try

Choose the correct answer:

1. Why is ammonia considered one of the world's most important industrial chemicals?

A. It is the main source of nitrogen for producing fertilizers.

B. It is the strongest acid.

C. It reacts with every metal.

D. It is the main component of air.

……

2. Which catalyst is used in the Haber–Bosch process?

A. Platinum

B. Iron(II,III) oxide (Fe_3O_4)

C. Manganese dioxide

D. Vanadium(V) oxide

3.Answer the following questions.

(a)Write the balanced chemical equation for the industrial production of ammonia.

(b)Write the three balanced chemical equations for the industrial production of nitric acid from ammonia. Also, name the catalyst required for each stage, if any.

(c)Write the overall balanced chemical equation for the process described in (b).

(d)Name the industrial process described in (a).

(e)Name the industrial process described in (b).

Be Global Citizen

Nitrogen and phosphorus compounds improve crop production, but excessive use can pollute rivers, lakes, and oceans by causing eutrophication, where excess nutrients lead to rapid algal growth and reduced oxygen levels for aquatic life.

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4.Identify each of the following statements as True or False.

(a)White phosphorus spontaneously ignites in the air.

(b)Tetraphosphorus decaoxide is an ionic crystal and is highly hygroscopic.

(c) When red phosphorus is burned, tetraphosphorus decaoxide is produced.

Think Critically

A country wants to increase food production by using much larger amounts of nitrogen and phosphorus fertilizers. A scientist warns that excessive fertilizer use may damage nearby rivers and lakes.

Evaluate the Situation

• What benefits could increased fertilizer use provide?

……

• What environmental problems could occur?

……

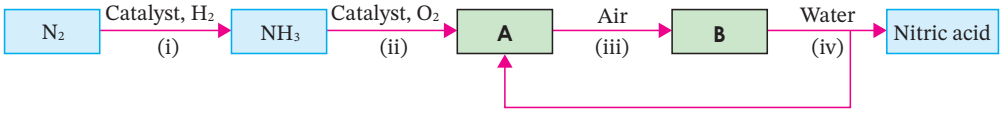
• How can chemistry help balance food production with environmental sustainability?

……

Use scientific evidence to justify your answers.

Exercise

1. The following figure shows the process of industrial manufacturing of nitric acid. Answer the following questions.



(a) .Write the catalysts used in reactions (i) and (ii), respectively, with their chemical formulas

(b) Identify the chemical formulas for substances A and B.

(c) Write balanced chemical equations for reactions (i) through (iv).

(d) Write the names of the industrial manufacturing processes for reaction (i) and reactions (ii) to (iv), respectively.

2. Among the following descriptions from (i) to (iv), choose two correct ones and answer with their numbers.

(i) White phosphorus is highly toxic and spontaneously ignites, so it is stored in water.

(ii) When red phosphorus is burned, white phosphorus is produced.

(iii) Tetraphosphorus decaoxide is an ionic crystal and is highly hygroscopic.

(iv) Some salts of phosphoric acid are used as fertilizers.

Challenge Your Thinking

A scientist says:

"Without the Haber–Bosch process, nearly half of the world's food production would not be possible."

Evaluate this statement.

• What scientific evidence supports this claim?

……

• What challenges result from relying heavily on synthetic fertilizers?

……

• How could future chemical technologies make fertilizer production more sustainable?

……

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Lesson 3-5 — Carbon, Silicon and Their Compounds

Engaging Introduction

Every day, carbon compounds affect our lives in ways we often do not notice. Carbon dioxide helps plants grow and is found in soft drinks, while carbon monoxide is an invisible poisonous gas that can be produced by faulty heaters or poorly ventilated kitchens. At the same time, silicon compounds are found in smartphones, computer chips, glass, building materials, and even the small packets labeled "Do Not Eat" inside new shoes and electronic devices.

Although carbon and silicon belong to the same group in the periodic table, their compounds have very different properties and applications. Understanding these differences helps scientists design safer materials, protect human health, and develop modern technologies.

Guiding Question How do the properties of carbon and silicon compounds determine their uses in daily life and their impact on human health and the environment?

Exploration

Consider these familiar situations:

- A family opens the windows while using a gas heater.
- A plant grows by absorbing carbon dioxide from the air.
- Small packets inside shoe boxes keep products dry.

Observation: What do these situations have in common?

……

Inference: Why is one carbon compound essential for life while another can be deadly?

……

Prediction: Why do manufacturers place silica gel packets inside many packaged products?

……

Point!

1. Carbon C

(a) Allotropes of carbon

Carbon has allotropes such as diamond, graphite, and fullerene.

(b) Carbon compounds

(i) Carbon monoxide CO

- A colourless, odourless, toxic gas.
- It is poorly soluble in water.

Structure of Science

Key fact :

- Carbon monoxide is a toxic gas
- Carbon dioxide is essential for photosynthesis and the carbon cycle.
- Silicon is one of the most abundant elements in Earth's crust.

Key concepts:

Incomplete Combustion
- Reducing Agent
- Silica Gel
- Semiconductor
- Adsorptionpressure

- Gas pressure
-

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- Has a **reducing** property, and reduces other substances by removing their oxygen, becoming carbon dioxide in the process.
- Burns with a pale blue flame in the air.
- Obtained by dehydrating **formic acid** HCOOH with concentrated sulfuric acid.

$$HCOOH \longrightarrow CO + H_2O$$

(ii) Carbon dioxide **CO_2**

- A colourless, odourless gas.
- **Sparingly soluble** in water. The aqueous solution is **weakly** acidic.
- Generated when **hydrochloric acid** is added to limestone (main component $CaCO_3$).

$$CaCO_3 + 2HCl \longrightarrow CaCl_2 + H_2O + CO_2$$

- The solution **turns milky white** when the gas is passed through an aqueous calcium hydroxide solution (limewater).
- The solid is called **dry ice** .

Think Critically

A family installs a carbon monoxide detector in their home but believes opening a window is unnecessary when using a charcoal heater indoors.

Evaluate the Situation

Is the family's reasoning scientifically correct?

……

Why can carbon monoxide accumulate indoors?

……

What evidence supports the use of both ventilation and carbon monoxide detectors?

……

Use scientific evidence to justify your answers.

……

2. Silicon Si

(a) Elemental silicon

- A covalent crystal with the same structure as diamond.
- Does not exist in nature.
- Obtained by melting silicon dioxide SiO_2 and reducing it with carbon.
- Exhibits the properties of a **semiconductor** .

Has electrical conductivity intermediate between "conductors" like metals and "insulators" like rubber.

(b) Silicon compounds

(i) Silicon dioxide **SiO_2**

- Exists in nature as quartz and rock crystal.
- Exhibits electrical insulation properties.

(ii) Sodium silicate Na_2SiO_3

- Produced by reacting silicon dioxide with sodium hydroxide or sodium carbonate.
- When water is added and heated, it forms a viscous liquid known as a **sodium silicate solution** .

(iii) Silica gel

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• A porous solid used as an adsorbent and desiccant.
Has many small holes and a large surface area.

• Produced by heating and drying silicic acid H_2SiO_3, which is generated when hydrochloric acid is added to sodium silicate solution.

Life Application

The Toxicity of Carbon Monoxide

Carbon monoxide (CO) is a colourless and odourless gas, making it extremely difficult to detect when generated. Hemoglobin, found in red blood cells, normally plays the role of binding to oxygen and transporting it throughout the body. However, CO binds to hemoglobin much more strongly—over 200 times stronger—than oxygen does.
Once CO binds, hemoglobin can no longer bind to oxygen, and oxygen transport is severely inhibited. As a result, the entire body falls into a state of severe oxygen deprivation (carbon monoxide poisoning). Because CO is produced by the incomplete combustion of fuels in poorly ventilated environments with an insufficient oxygen supply, it is essential to always ensure adequate ventilation when using combustible fuels.

Warm Up

Answer the following questions.

(a) Identify the appropriate words or substance names for A to C in the following passage.

Carbon dioxide is usually generated in the laboratory by adding (A) to limestone. On the other hand, carbon monoxide is usually produced in the laboratory by adding concentrated sulfuric acid to (B) and heating. When carbon dioxide is passed through (C) , it turns milky white.

(b) In the reaction underlined in **(a)**, what is the role of concentrated sulfuric acid? Briefly explain by referring to the specific property of concentrated sulfuric acid.

(c) Which of the following statements (A to D) is incorrect?

A. Elemental silicon is obtained by reducing silicon dioxide.

B. Silica gel is used as a desiccant and adsorbent.

C. When water is added to sodium silicate and heated, it forms a sodium silicate solution.

D. Silicon dioxide exhibits the properties of a semiconductor.

Explanation

(a) A: hydrochloric acid.

B: formic acid.

When concentrated sulfuric acid is added to formic acid, the formic acid is dehydrated to produce carbon monoxide.

C: aqueous calcium hydroxide solution (limewater).

(b) It acts as a dehydrating agent. Concentrated sulfuric acid has a strong dehydrating property, which removes hydrogen and oxygen atoms from formic acid (HCOOH) in the form of water (H_2O), resulting in the formation of carbon monoxide (CO).

(c) D. Elemental silicon exhibits semiconductor properties, whereas silicon dioxide is an electrical insulator.

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Data Interpretation Activity

Analyze the Properties

Substance	Observation
Carbon monoxide	Toxic, colorless gas
Carbon dioxide	Turns limewater milky
Silica gel	Absorbs moisture
Silicon	Semiconductor

Think Like a Chemist

Which substance is used to detect carbon dioxide? .....

Which substance removes moisture from the air? .....

Which compound presents the greatest health risk? .....

What evidence supports your answers?

Try

Choose the correct answer:

1. Why is silica gel placed inside product packaging?

A. To add fragrance

B. To absorb moisture

C. To cool the product

D. To produce oxygen

.....

2 . Which reagent is commonly used to identify carbon dioxide gas?

A. Hydrochloric acid

B. Limewater

C. Sodium hydroxide

D. Silver nitrate

.....

3. Identify the appropriate words or substance names for the blank spaces in the following passage.

Carbon monoxide is (i) soluble in water, and is a colourless, odourless, (ii) gas. High-temperature carbon monoxide has a strong (iii) property and brings about the (iii) of metal oxides. Carbon monoxide is obtained by adding (iv) to (v) and heating. Carbon dioxide is sparingly soluble in water and ionizes to become (vi). Therefore, the aqueous solution is weakly (vii). Calcium hydroxide $Ca(OH)_2$ is used for the detection of carbon dioxide. When put into limewater, calcium carbonate $CaCO_3$ is produced, turning the limewater (viii).

4. Identify each of the following statements as True or False.

(i) Silicon is abundant in the earth's crust and occurs naturally as a free element.

(ii) Elemental silicon has the same crystal structure as graphite.

(iii) When silicic acid is heated and dried, porous silica gel is obtained.

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Exercise

1. Identify the appropriate words or substance names for the blank spaces in the following passage.

Carbon oxides include carbon monoxide and carbon dioxide. Carbon monoxide is produced by the incomplete combustion of carbon, and can also be obtained by adding concentrated sulfuric acid to (i) and heating. Carbon monoxide is highly toxic and is (ii) soluble in water. It also has a strong reducing property at high temperatures.

Carbon dioxide is obtained by adding (iii) to calcium carbonate. Carbon dioxide is sparingly soluble in water and exhibits weak acidity. Also, when carbon dioxide is passed through limewater, it turns (iv). Solid carbon dioxide is called (v), and when left at room temperature, it changes directly from a solid to a gas.

2. For each of the following statements, indicate whether the underlined part is True or False. If False, provide the correct term.

(i) When silicic acid is heated and dried, silica gel is obtained.

(ii) When hydrochloric acid is added to a sodium silicate solution, silicic acid is produced.

(iii) When silicon dioxide and sodium chloride are melted, sodium silicate is produced.

Engineering Challenge

You are designing packaging for electronic devices that will be shipped to a humid country.

Which material would you include to protect the electronics? Explain your decision using scientific evidence.

.....

.....

.....

Sustainability Connection

The Solvay Process demonstrates several principles of sustainable chemistry.

✓ Carbon dioxide is recycled.

✓ Ammonia is regenerated and reused.

✓ Raw material consumption is reduced.

✓ Less industrial waste is released.

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Lesson 3-6 — Alkali Metals and Their Compounds

Engaging Introduction

Imagine baking a cake at home. As the mixture heats, tiny bubbles form, making the cake soft and fluffy. The secret ingredient is baking soda (sodium hydrogen carbonate), which releases carbon dioxide when heated.

Now imagine a water treatment plant producing millions of kilograms of sodium compounds every year for making glass, detergents, medicines, and clean drinking water. Chemists must carefully design manufacturing processes that recycle chemicals and reduce waste to make these products sustainably.

In this lesson, you will explore why alkali metals are among the most reactive elements on Earth and discover how chemistry transforms common salt into some of the world's most useful materials.

Guiding Question How can one highly reactive element—sodium—be transformed into many useful compounds that support everyday life and sustainable industry?

Exploration

Think about these familiar situations:

Bread becomes soft after baking.

Antacid tablets fizz when dropped into water.

Table salt looks harmless, but metallic sodium reacts violently with water.

Without studying the lesson:

• Why is metallic sodium dangerous while table salt is safe?

.....

• Why does baking soda produce bubbles during baking?

.....

• Why do industries recycle carbon dioxide during the manufacture of sodium carbonate?

.....

Point!

1. Alkali Metals

(a) Alkali metals: Li, Na, K, Rb (rubidium), Cs (caesium), and Fr (francium) in Group 1 of the periodic table, excluding H.

(b) Properties of alkali metals

(i) All are **silvery-white** metals with **low** density.

Structure of Science

Key fact :

• Alkali metals are highly reactive because they lose one valence electron easily.

• Sodium forms many important compounds with different chemical properties.

Key Concepts:

• Alkali Metals
• Reactivity
• Electrolysis
• Sodium Hydroxide
• Sodium Hydrogen Carbonate
• Sodium Carbonate
• Thermal Decomposition
• Industrial Recycling
• Solvay Process

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(ii) Melting points are **low** .

(iii) The elements are obtained by molten salt electrolysis of their compounds

(iv) They impart characteristic colours to a flame during a **flame test** .

(v) React violently with water at room temperature to generate **hydrogen** .

(vi) Because they react immediately with water and oxygen in the air, they are stored under **kerosene** .

life application

Chemistry in Your Kitchen

Many household products contain sodium compounds.

Product	Sodium Compound	Why it is Used
Baking powder	Sodium hydrogen carbonate	Releases CO_2 to make cakes rise
Soap	Sodium hydroxide	Produces strong cleaning agents
Laundry detergent	Sodium carbonate	Softens hard water
Antacid tablets	Sodium hydrogen carbonate	Neutralizes excess stomach acid

2. Compounds of Sodium Na

(a) Sodium hydroxide **NaOH**

- Produced when sodium reacts with water. $2Na + 2H_2O \longrightarrow 2NaOH + H_2$
- A **white** solid.
- Highly soluble in water, and the aqueous solution is **strongly basic** .
- It is highly deliquescent (absorbs moisture from the air and dissolves).

(b) Sodium hydrogen carbonate **$NaHCO_3$**

- A **white** powder, also called **baking soda** (sodium bicarbonate).
- Sparingly soluble in water, and the aqueous solution is **basic** .
- Used in baking powder, gastrointestinal medicine, etc.

(c) Sodium carbonate **Na_2CO_3**

- A **white** solid.
- Highly soluble in water, and the aqueous solution is **basic** .
- Industrially manufactured by the **Solvay process** .

⟨Solvay Process⟩

❶ When ammonia is dissolved in a saturated aqueous solution of sodium chloride and carbon dioxide is passed through, sodium hydrogen carbonate precipitates.

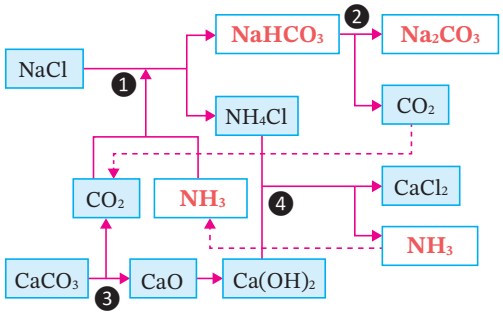
$$NaCl + H_2O + NH_3 + CO_2 \longrightarrow NaHCO_3 + NH_4Cl$$

❷ When this precipitate is thermally decomposed, sodium carbonate is obtained.

$$2NaHCO_3 \longrightarrow Na_2CO_3 + H_2O + CO_2$$

❸ The carbon dioxide generated in reaction ❷ is reused in reaction ❶. Furthermore, limestone CaCO3 is decomposed to obtain carbon dioxide.

$$CaCO_3 \longrightarrow CaO + CO_2$$



Sustainability Connection

The Solvay Process demonstrates several principles of sustainable chemistry.

✓ Carbon dioxide is recycled.

✓ Ammonia is regenerated and reused.

✓ Raw material consumption is reduced.

✓ Less industrial waste is released.

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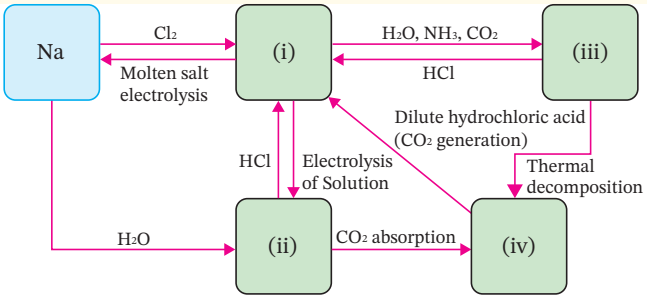
❹ Ammonia is regenerated by reacting ammonium chloride (produced in step ❶) with calcium hydroxide. The calcium hydroxide is obtained by reacting calcium oxide (from step ❸) with water. The regenerated ammonia is then reused in step ❶.

$$Ca(OH)_2 + 2NH_4Cl \longrightarrow CaCl_2 + 2H_2O + 2NH_3$$

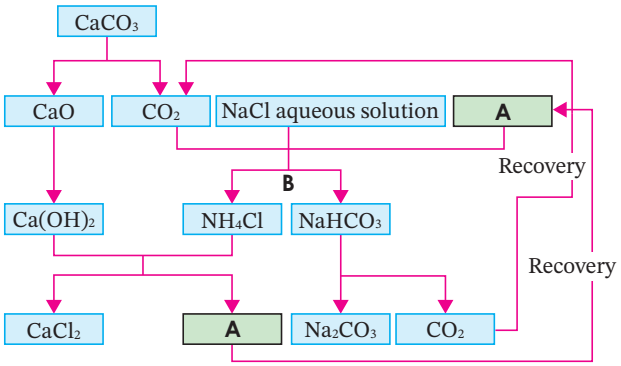
Warm Up

Answer the following questions.

(a) The figure on the right shows the relationship between sodium and its compounds. Identify the chemical formulas for the substances (i) through (iv).



(b) The figure on the right outlines the industrial manufacturing process of sodium carbonate. However, water is omitted from the figure. Answer the following questions regarding this.



(i) What is this manufacturing process called?

(ii) Identify the chemical formula for the substance A.

(iii) Write the balanced chemical equation for the reaction occurring in step B.

Explanation

(a) State the compound of sodium Na produced in each reaction.

(i) Sodium reacts with chlorine according to the following equation:

$$2Na + Cl_2 \longrightarrow 2NaCl$$ Answer: NaCl

(ii) Sodium reacts with water according to the following equation:

$$2Na + 2H_2O \longrightarrow 2NaOH + H_2$$ Answer: NaOH

(iii) Sodium chloride reacts with water, ammonia, and carbon dioxide according to the following equation:

$$NaCl + H_2O + NH_3 + CO_2 \longrightarrow NaHCO_3 + NH_4Cl$$

Answer: $NaHCO_3$

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(iv) Sodium hydrogen carbonate undergoes thermal decomposition according to the following equation:

$$2NaHCO_3 \longrightarrow Na_2CO_3 + H_2O + CO_2$$ Answer: Na_2CO_3

(b) (i) Solvay process

(ii) As shown in the figure, calcium hydroxide reacts with ammonium chloride according to the following equation:

$$Ca(OH)_2 + 2NH_4Cl \longrightarrow CaCl_2 + 2H_2O + 2NH_3$$

Therefore, NH_3.

(iii) $NaCl + H_2O + NH_3 + CO_2 \longrightarrow NaHCO_3 + NH_4Cl$

NOS: Identifying Variables

A chemical engineer wants to increase the sustainability of a sodium carbonate factory.

Challenge

How can the factory reduce waste while maintaining production?

Investigation

Predict which substances can be recovered and reused.

What is the independent variable?

.....

What is the dependent variable?

.....

Which variables should be controlled to ensure a fair test?

.....

Data Interpretation

A factory records the following information:

Process Step	CO_2 Used (kg)	CO_2 Recovered (kg)
Initial reaction	100	—
Thermal decomposition	—	42
Limestone heating	—	51

Think Like a Chemist

Why is CO_2 recovered instead of discarded? .....

Which reaction supplies additional CO_2? .....

How does recycling improve industrial efficiency? .....

Try

1. Which of the following statements about alkali metals are correct?

A. Alkali metal compounds impart characteristic colours to a flame during a flame test.

B. Many of the elements have high melting points and low densities.

C. The elements hardly react with water at room temperature, but react with hot water.

D. Elemental sodium is stored under kerosene.

E. Sodium hydroxide and sodium carbonate, which are compounds of sodium, are both white solids.

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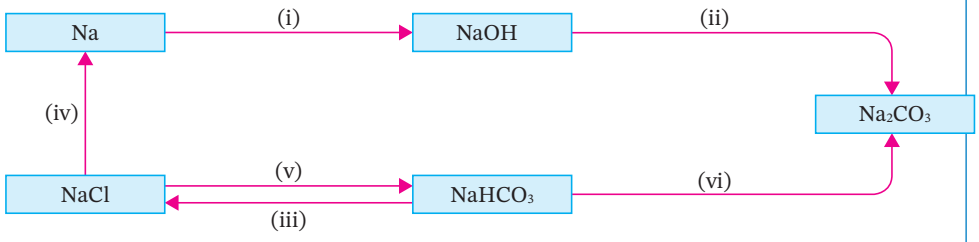
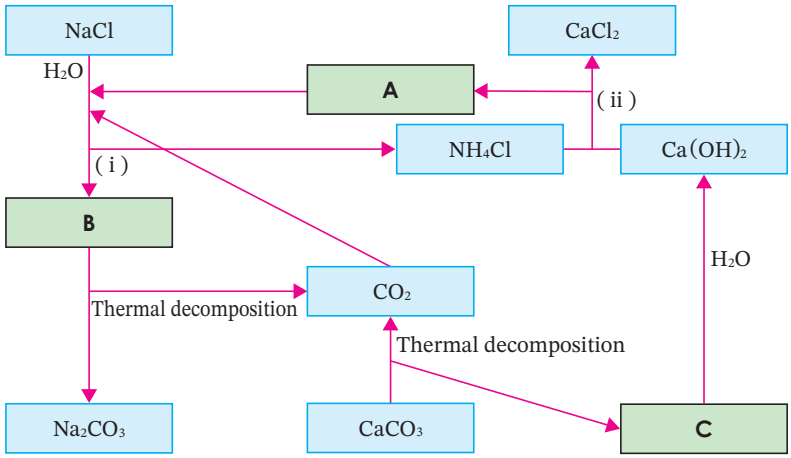
2.The following figure shows compounds obtained from sodium. Select the appropriate operations for (i) through (vi) from A to F below.



(A) Absorb CO_2 **(B)** Add HCl **(C)** Molten salt electrolysis

(D) Heat the solid **(E)** Add NH_3, H_2O, and CO_2 **(F)** Add water

3. Sodium carbonate is industrially manufactured as shown in the following figure. Answer the questions below regarding this.



(a) Name the industrial process used to manufacture sodium carbonate.

(b) Write the chemical formulas of the substances that correspond to A, B, and C in the figure.

(c) Write the chemical equations for (i) and (ii) in the figure.

Grand Challenge

A company plans to build a new sodium carbonate factory.
Two proposals are suggested.
Factory A
Releases all carbon dioxide into the atmosphere.
Factory B
Recovers and recycles carbon dioxide and ammonia.
Evaluate the designs.
Which factory is more sustainable? .....
Which factory would produce less waste? .....

Use scientific evidence to justify your conclusions. .....

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Exercise

Choose the correct answer.

1. Why is metallic sodium stored under kerosene?

A. To increase its melting point.

B. To prevent reaction with air and moisture.

C. To improve electrical conductivity.

D. To reduce its density.

.....

2. During the Solvay Process, which substance is regenerated and reused?

A. Sodium chloride

B. Carbon dioxide

C. Calcium chloride

D. Hydrogen

.....

3. Which of the following statements about alkali metals are correct?

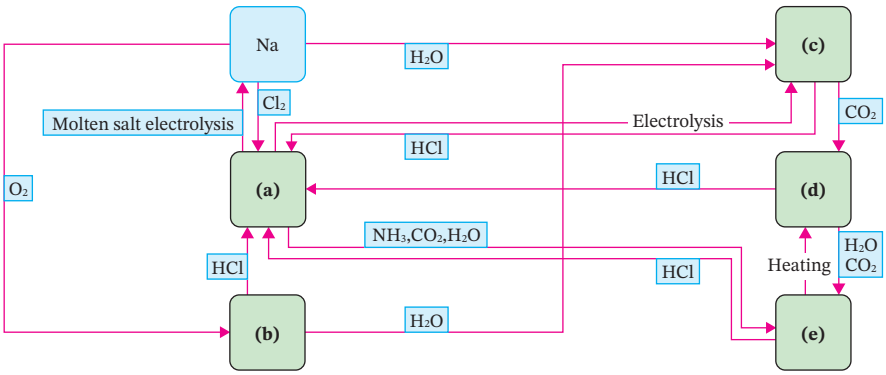
A. Many elemental alkali metals have high melting points and high densities.

B. Because elemental alkali metals react immediately with oxygen in the air, they are stored in water.

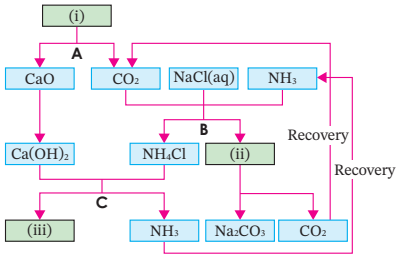
C. Sodium hydroxide is strongly basic and highly deliquescent.

D. The hydrogen carbonate salt of sodium is called baking soda and is used in baking powder, etc.

4. The figure below shows the relationship between sodium and its compounds. Identify the chemical formulas for the substances **(a)** through **(e)**.



4. The Figure on the right outlines the flow of the industrial manufacturing process of sodium carbonate. However, water is omitted from the figure. Answer the following questions.



(a) Name this industrial process.

(b) Identify the chemical formulas for substances (i) through (iii).

(c) Write the balanced chemical equations for the reactions occurring in steps A, B, and C.

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Lesson 3-7 — Alkaline Earth Metals and Their Compounds

Engaging Introduction

Imagine walking into a magnificent limestone cave filled with towering stalactites and stalagmites that have taken thousands of years to form. Now imagine workers at a construction site mixing quicklime with water to prepare building materials. Although these situations seem completely different, they are connected by the chemistry of calcium compounds.

From caves and seashells to cement, drinking water, agriculture, and environmental protection, calcium compounds play an essential role in both nature and modern society.

In this lesson, you will discover how simple chemical reactions create remarkable natural landscapes and support many technologies that improve our daily lives.

Guiding Question How can the chemistry of calcium explain both the formation of natural limestone caves and the production of materials used in modern construction?

Exploration

Materials

- Limewater (calcium hydroxide solution)
- Straw (or CO_2 generator)
- Two test tubes
- Stopwatch

Procedure

1. Pour equal amounts of limewater into two test tubes.
2. Bubble air through the first tube for 30 seconds.
3. Bubble exhaled air (rich in CO_2) through the second tube.
4. Continue bubbling for another minute.
5. Compare the appearance of both solutions.

What is your observation?.....

What is your conclusion?.....

Point!

1. Alkaline Earth Metals

(a) Alkaline earth metals: Be, Mg, Ca, Sr (Strontium), Ba (Barium), and Ra (Radium) in Group 2 of the periodic table.

(b) Properties of alkaline earth metals

(i) Silvery-white metals.

Structure of Science

Key fact :

- Magnesium and calcium belong to Group 2 and usually form +2 ions.
- Calcium compounds continuously transform between solid and dissolved forms.

Key concepts:

- Alkaline Earth Metals
- Divalent Ions
- Calcium Cycle
- Limewater
- Quicklime
- Slaked Lime
- Carbonate
- Hydrogen Carbonate
- Solubility
- Hard Water Vacuum.

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(ii) Compared to alkali metals in the same period, their metallic bonds are **stronger**, their melting points are **higher**, and their densities are **higher**.

(iii) Properties of magnesium Mg

- **Barely reacts** with water at room temperature. Reacts with hot water to form a **weakly basic** hydroxide.
- Magnesium carbonate is **poorly soluble** in water and **dissolves** in hydrochloric acid.
- **Does not impart** a characteristic colour in a flame test.

(iv)Properties of calcium Ca

- Reacts with water at room temperature to generate hydrogen and forms a **strongly basic** hydroxide.
- Calcium carbonate is **poorly soluble** in water and **dissolves** in hydrochloric acid.
- **Imparts** a characteristic colour in a flame test.

2. Compounds of Calcium

(a) Calcium oxide **CaO**

Oxides of calcium

$2Ca + O_2 \longrightarrow 2CaO$

- A white solid also called **quicklime**.
- Obtained by strongly heating limestone (main component $CaCO_3$).

(b) Calcium hydroxide **$Ca(OH)_2$**

- A white powder also called **slaked lime**.
- Produced when calcium oxide reacts with water.

$CaO + H_2O \longrightarrow Ca(OH)_2$

- Sparingly soluble in water, and its aqueous solution is **strongly basic**.
- The saturated aqueous solution is called **limewater**.

(c) Calcium carbonate **$CaCO_3$**

- Abundantly exists in nature as the main component of limestone, marble, shells, etc.
- Produced as a white precipitate when carbon dioxide is passed through limewater.

$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$

- If carbon dioxide is continuously passed through a cloudy white suspension of $CaCO_3$, **calcium hydrogen carbonate $Ca(HCO_3)_2$** is produced, and the suspension clears.

  In nature, water containing carbon dioxide dissolves $CaCO_3$ such as limestone, sometimes forming limestone caves.

  Conversely, when carbon dioxide is released from an aqueous solution containing **$Ca(HCO_3)_2$**, **$CaCO_3$** precipitates. By repeating this, stalactites and stalagmites form in limestone caves.

(d) Calcium sulfate **$CaSO_4$**

- Occurs in nature as calcium sulfate dihydrate $CaSO_4 \cdot 2H_2O$ (gypsum).

Misconception Alert

✗ Wrong idea:

„Limewater and limestone are the same substance."

✓ Correct:

Limewater is a solution of calcium hydroxide.

Limestone is solid calcium carbonate.

Sustainability Connection

Calcium compounds contribute to sustainable development by:

- Purifying drinking water.
- Neutralizing acidic soils.
- Supporting environmentally friendly construction materials.

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(e) Bleaching powder $CaCl(ClO) \cdot H_2O$

• Obtained by reacting solid calcium hydroxide ($Ca(OH)_2$) with chlorine gas (Cl_2).

• Acts as an oxidising agent.

life application

Calcium All Around Us

Calcium compounds are found in many everyday products.

Compound	Everyday Use
Calcium oxide	Air Pollution Control
Calcium hydroxide	Water treatment
Calcium carbonate	Building stones, Cement Manufacturing
Gypsum	Medical casts and drywall
Bleaching powder	Swimming pool disinfection

Warm Up

Answer the following questions.

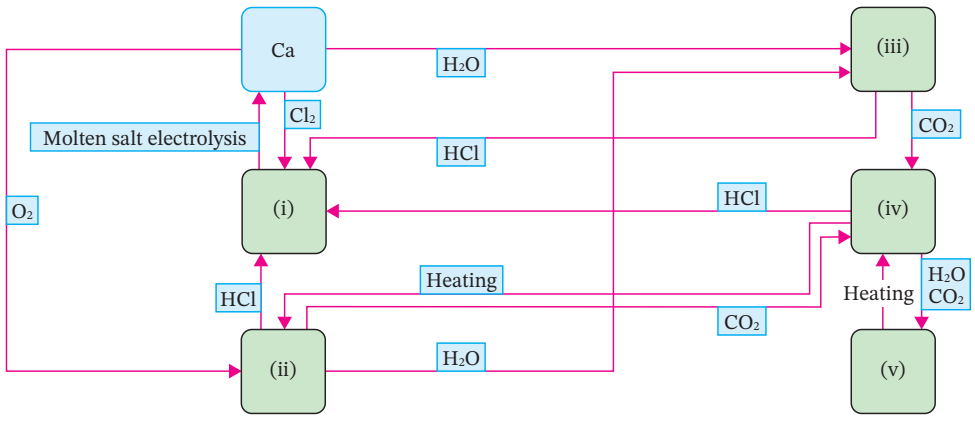
(a) For each of the following properties, indicate whether it applies only to calcium (A), only to magnesium (B), or to both (C).

(i) The aqueous solution of its hydroxide is strongly basic.

(ii) Its carbonate dissolves in hydrochloric acid.

(iii) Easily forms divalent cations.

(b) Identify the chemical formulas for substances (i) through (v) shown in the following figure.



Explanation

(a) (i) Magnesium reacts with hot water to form a weakly basic hydroxide. (A)

(ii) Both calcium carbonate $CaCO_3$ and magnesium carbonate $MgCO_3$ react with strong acids like hydrochloric acid to dissolve and generate carbon dioxide. (C)

(iii) Both calcium and magnesium are alkaline earth metals. Alkaline earth metals are in Group 2 of the periodic table, have 2 valence electrons, and easily form divalent cations. (C)

(b) State the compound of calcium Ca produced in each reaction.

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(i) Calcium reacts with chlorine according to the following equation:

$$Ca + Cl_2 \longrightarrow CaCl_2$$ Answer: $CaCl_2$

(ii) Calcium reacts with oxygen according to the following equation:

$$2Ca + O_2 \longrightarrow 2CaO$$ Answer: CaO

(iii) Calcium oxide reacts with water according to the following equation:

$$CaO + H_2O \longrightarrow Ca(OH)_2$$ Answer: $Ca(OH)_2$

(iv) Calcium hydroxide reacts with carbon dioxide according to the following equation:

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$$ Answer: $CaCO_3$

(v) Calcium carbonate reacts with water and carbon dioxide according to the following equation:

$$CaCO_3 + H_2O + CO_2 \rightleftharpoons Ca(HCO_3)_2$$ Answer: $Ca(HCO_3)_2$

Data Interpretation

Analyze Experimental Results

Experiment	Observation
Bubble CO_2 into limewater	White precipitate forms
Continue bubbling CO_2	Solution becomes clear

Think Like a Chemist

Why did the white precipitate first appear?

.....

Why did it disappear later?

.....

Which compound became soluble?

.....

Try

Choose the correct answer:

1. Which calcium compound is commonly called quicklime?

A. $CaCO_3$

B. CaO

C. $Ca(OH)_2$

D. $Ca(HCO_3)_2$

.....

2. Which calcium compound is responsible for turning limewater milky?

A. $Ca(HCO_3)_2$

B. $CaSO_4$

C. $CaCO_3$

D. $CaCl_2$

.....

3. Which of the following statements (A to D) applies to magnesium but not to calcium?

A. Its carbonate is soluble in water.

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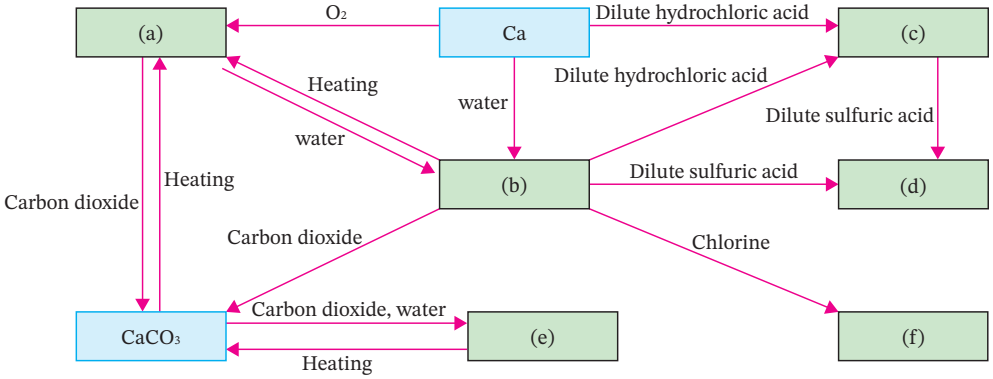
B. Does not impart a characteristic colour in a flame test.

C. The element reacts easily with water at room temperature.

D. Its hydroxide is highly soluble in water.

4. The following diagram shows elemental calcium and its compounds. Answer the questions below.



(A) Identify the chemical formulas and names for compounds (a) through (f).

(B) Which two of the following statements (i to vi) regarding compounds (a) through (f) are incorrect?

(i) (a) is a white solid called quicklime.

(ii) (b) is called slaked lime, and its aqueous solution is weakly basic.

(iii) (c) is the salt produced when the aqueous solution of (b) and hydrochloric acid are neutralized.

(iv) The dihydrate of (d) exists naturally as gypsum.

(v) An aqueous solution of (e) is formed in the process of a limestone cave forming.

(vi) (f) acts as a reducing agent.

Grand Challenge

A city plans to restore an old limestone monument damaged by acid rain.
As a materials scientist:
Explain why limestone is damaged by acid rain.
.....
Suggest a calcium compound that could help repair or protect the structure.
.....

Why is understanding calcium chemistry important for protecting cultural heritage?
.....
Support your answers using scientific evidence.
.....

Exercise

1. For each of the following properties, indicate whether it applies only to Mg (A), only to Ca (B), or to both (C).

(a) Easily forms divalent cations.

(b) Does not react with water at room temperature, but reacts with hot water.

(c) Its carbonate is poorly soluble in water.

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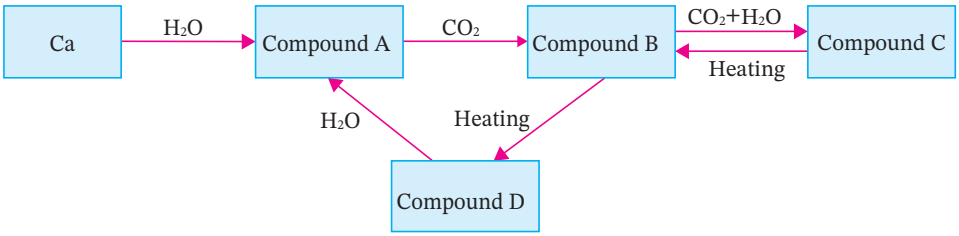
(d) Its hydroxide dissolves in water and its aqueous solution is strongly basic.

2. The following diagram shows elemental calcium and its compounds. Answer the questions below.



(a) Identify the chemical formulas and names for compounds A through D.

(b) Which of the following statements (i) to (iv) regarding compounds A through D is incorrect?

(i) Compound A is sparingly soluble in water, and its aqueous solution is weakly basic.

(ii) Compound B exists widely in nature as the main component of limestone and marble.

(iii) In a limestone cave, compound B precipitates from the aqueous solution of compound C, and limestone formations grow.

(iv) Compound D is called quicklime, and because it generates heat when reacting with water, it is used as a heating agent.

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Lesson 3-8 — Representative Metals other than Groups 1 and 2

Engaging Introduction

Imagine drinking a soft drink from an aluminium can. Later, you use zinc-coated steel to protect a bicycle from rust, while a rechargeable lead-acid battery starts a car.

These metals look ordinary, but they behave in surprising ways. Unlike most metals, some can react with both acids and alkalis, while others form colourful chemical species called complex ions that chemists use in laboratories and industry.

In this lesson, you will discover why some metals have "double personalities" and how chemists use these unusual reactions to solve real-world problems.

Guiding Question Why can some metals react with both acids and bases while most metals cannot?

Structure of Science

Key fact :

The chemical behaviour of many metals depends on their electron configuration and their ability to form coordinate bonds and complex ions.

Key concepts:

Complex ion
- Coordinate bond
- Amphoteric metal
- Amphoteric oxide
- Ligands
- Precipitation reactions

Exploration

A student performs the following experiment:

Aluminium chloride solution is mixed with sodium hydroxide.

→ A white gel-like precipitate appears.

Then the student keeps adding more sodium hydroxide.

Suddenly...

The white precipitate disappears!

The same phenomenon happens with zinc ions.

Think before studying

- Why did the precipitate first appear?.....
- Why did it disappear after adding more sodium hydroxide?.....
- Where did the solid go?.....

Point!

1. Complex Ions

Complex ion : An ion formed by molecules or anions (Ligands) forming coordinate bonds with a metal ion.
The chemical formula is expressed using [ ].

Example: $[Fe(CN)_6]^{4-}$ Hexacyanidoferrate (II) ion
→A complex ion formed from an iron (II) ion Fe^{2+} and cyanide ions CN^-.

2. Aluminium Al

(a) Elemental aluminium

- Belongs to Group **13** of the periodic table and has **3** valence electrons.
- Industrially, it is produced by **molten salt electrolysis** of aluminium oxide purified

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from bauxite .

• Reacts with aqueous solutions of acids and strong bases to generate hydrogen .

Example: • Reaction with hydrochloric acid: $2Al + 6HCl \longrightarrow 2AlCl_3 + 3H_2$

• Reaction with sodium hydroxide:

$$2Al + 2NaOH + 6H_2O \longrightarrow 2Na[Al(OH)_4] + 3H_2$$

Sodium tetrahydroxidoaluminate

Note: A metal that reacts with both acidic and strongly basic aqueous solutions is called an amphoteric metal .

(b) Compounds of aluminium

(i) Aluminium oxide Al_2O_3

• A white powder produced when aluminium is heated in oxygen.

• Soluble in aqueous solutions of acids and strong bases.

Note: An oxide that is soluble in both acidic and strongly basic aqueous solutions is called an amphoteric oxide .

(ii) Aluminium hydroxide $Al(OH)_3$

• Produced as a white gel-like precipitate when a base is added to an aqueous solution containing aluminium ions Al^{3+}.

• Soluble in aqueous solutions of acids and strong bases.

Example: • Reaction with hydrochloric acid:

$Al(OH)_3 + 3HCl \longrightarrow AlCl_3 + 3H_2O$

• Reaction with sodium hydroxide: $Al(OH)_3 + NaOH \longrightarrow Na[Al(OH)_4]$

→ When an excess of sodium hydroxide aqueous solution is added, tetrahydroxidoaluminate ions $[Al(OH)_4]^-$ are produced.

Note: A hydroxide that is soluble in both acidic and strongly basic aqueous solutions is called an amphoteric hydroxide .

3. Zinc Zn

(a) Reactions of zinc

• Belongs to group (12), Has to Valence electrons

• Reacts with aqueous solutions of acids and strong bases to generate hydrogen . •

Zinc is an amphoteric metal.

• When burned, it produces white powdered zinc oxide ZnO .

(b) Reactions of zinc ion Zn^{2+}

• Adding a small amount of aqueous sodium hydroxide or aqueous ammonia: Precipitate of zinc hydroxide $Zn(OH)_2$ forms.

• Adding excess aqueous sodium hydroxide:
Tetrahydroxidozincate(II) ions $[Zn(NH_3)_4]^{2+}$ form, resulting in a colourless aqueous solution.

Misconception Alert

Misconception 1

Aluminium behaves like all other metals.

Aluminium is amphoteric and reacts with both acids and strong bases.

Misconception 2

Complex ions are mixtures.

Complex ions are new chemical species formed through coordinate bonding.

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$$Zn(OH)_2 + 2OH^- \longrightarrow [Zn(OH)_4]^{2-}$$

- Adding excess aqueous ammonia:
  Tetraamminezinc(II) ions **$[Zn(NH_3)_4]^{2+}$** form, a colourless aqueous solution.

$$Zn(OH)_2 + 4NH_3 \longrightarrow [Zn(NH_3)_4]^{2+} + 2OH^-$$

- Passing hydrogen sulfide through:
  A **white** precipitate of zinc sulfide **ZnS** forms.

4. Tin Sn and Lead Pb

(a) Elemental tin and lead

- Belong to Group **14** of the periodic table and have **4** valence electrons.
- **Soluble** in aqueous solutions of acids and strong bases.

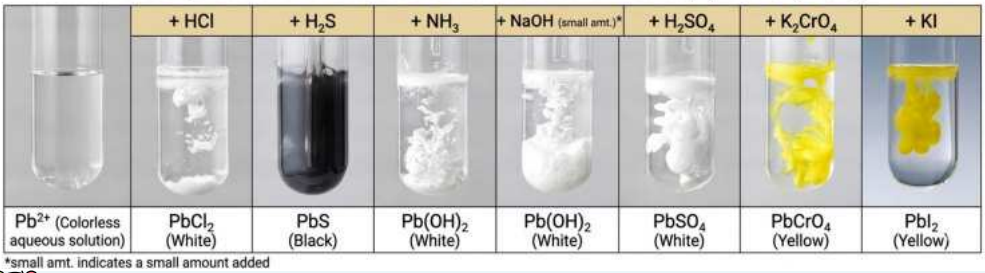
(b) Compounds of tin and lead

- Tin(II) chloride $SnCl_2$ is a strong **reducing** agent.
- Lead(IV) oxide PbO_2 is used as an **oxidising** agent in the positive electrode of a lead-acid battery, etc.
- Lead is poorly soluble in hydrochloric acid and dilute sulfuric acid because it forms an insoluble coating of
  lead(II) chloride ($PbCl_2$) and **lead(II) sulfate ($PbSO_4$)**, respectively.

(c) Reactions of Lead(II) Ions

Lead(II) ions (Pb^{2+}) react with various anions to form precipitates. While many lead compounds are insoluble in water, Lead(II) nitrate ($Pb(NO_3)_2$) and Lead(II) acetate ($(CH_3COO)_2Pb$) are soluble. Additionally, although Lead(II) chloride ($PbCl_2$) is insoluble in cold water, it dissolves in hot Water

Precipitation Reactions and Colors of Lead(II) Ions (Pb^{2+})



*small amt. indicates a small amount added

life application

Why Are Aluminium Cooking Pots Safe?

Aluminium reacts easily with acids and alkalis.

So why doesn't your cooking pot disappear?

Because aluminium instantly forms a thin layer of aluminium oxide (Al_2O_3) that protects the metal underneath.

This protective oxide layer is responsible for

✓ corrosion resistance
✓ lightweight aircraft
✓ food containers
✓ smartphones

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Warm Up

Answer the following questions.

(a) Identify the appropriate numbers or words for the parentheses (A and F), and the chemical formulas for the brackets [B, C, D, and E] in the following passage.

Aluminium is a main group element belonging to Group (A) of the periodic table, and the element reacts with hydrochloric acid, generating hydrogen and dissolving to form [B]. When aqueous ammonia is added to the solution of [B], a precipitate of [C] is formed. When hydrochloric acid is added to [C], it dissolves to become [D]. Also, when an aqueous sodium hydroxide solution is added to [C], it dissolves to become [E]. A hydroxide that dissolves in both acids and strong bases, like [C], is called an (F).

(b) Identify the chemical formulas for (A), (B), and (C) in the following passage.

Elemental zinc Zn reacts with both acids and strong bases to generate (A). When a small amount of aqueous ammonia is added to an aqueous solution containing zinc ions Zn^{2+}, a white precipitate of (B) is produced. Furthermore, when aqueous ammonia is added, a complex ion represented by (C) is produced.

(c) Identify the appropriate numbers or terms for (A) through (E) in the following passage. Provide specific substance names for (D) and (E).

Tin and lead are both elements belonging to Group (A) of the periodic table, and have (B) valence electrons. The elements (C) in aqueous solutions of acids and strong bases, but in the case of lead, it is difficult to dissolve because it forms poorly soluble salts of (D) in hydrochloric acid and (E) in dilute sulfuric acid.

Explanation

(a) A: 13

B: Write the chemical equation for the reaction of aluminium with hydrochloric acid.

$$2Al + 6HCl \longrightarrow 2AlCl_3 + 3H_2$$ Answer: $AlCl_3$ (Al^{3+})

C: When ammonia is added to an aqueous solution containing aluminium ions (such as $AlCl_3$), a white precipitate of aluminium hydroxide forms. Answer: $Al(OH)_3$

D: Write the chemical equation for the reaction of aluminium hydroxide with hydrochloric acid.

$$Al(OH)_3 + 3HCl \longrightarrow AlCl_3 + 3H_2O$$ Answer: $AlCl_3$ (Al^{3+})

E: Write the chemical equation for the reaction of aluminium hydroxide with sodium hydroxide.

$$Al(OH)_3 + NaOH \longrightarrow Na[Al(OH)_4]$$ Answer: $Na[Al(OH)_4]$ ($[Al(OH)_4]^-$)

F: Amphoteric hydroxide

(b) A: H_2 B: $Zn(OH)_2$ C: $[Zn(NH_3)_4]^{2+}$

(c) A: 14 B: 4 C: dissolve D: lead(II) chloride E: lead(II) sulfate

Think Like a Chemist

A wastewater treatment plant contains aluminium ions.

A technician accidentally adds too much sodium hydroxide.

Initially, a white precipitate forms.

After additional sodium hydroxide is added, the solution becomes clear again.

Explain:

Why did the precipitate disappear? .....

Which complex ion was produced? .....

Why is understanding this reaction important in water treatment? .....

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Try

1. Read the following text and answer the questions below.

When pure (A) obtained by chemically treating (B), an ore of aluminium, is subjected to molten salt electrolysis, elemental aluminium is obtained. When aluminium reacts with hydrochloric acid, it dissolves while generating (C) to become an aqueous solution of (D). Also, when an aqueous sodium hydroxide solution is gradually added to an aqueous solution containing Al^{3+}, a white gelatinous precipitate of (E) is first formed, but upon the addition of excess aqueous sodium hydroxide, this precipitate dissolves to form (F), resulting in a colourless and transparent aqueous solution.

(a) Identify the appropriate terms for A through D, and the chemical formulas for E and F.

(b) Write the balanced chemical equation for the reaction described in the underlined part.

(c) Write the balanced chemical equation for the reaction between (E) and hydrochloric acid.

(d) Write the balanced chemical equation for the reaction between (E) and sodium hydroxide.

2. Identify the appropriate term for (A) and the chemical formulas for [B] and [C] in the following passage.

When a small amount of aqueous sodium hydroxide is added to an aqueous solution containing zinc ions Zn^{2+}, a (A)-coloured precipitate of $Zn(OH)_2$ is produced, but when added in excess, it dissolves to form the complex ion [B]. Also, when aqueous ammonia is added to $Zn(OH)_2$, it dissolves to form the complex ion [C].

3. Identify the appropriate term for (A) and the chemical formulas for [B] and [C] to complete the following passage.

Lead is an (A) metal that dissolves in aqueous solutions of acids and strong bases, but the solid metal is poorly soluble in dilute sulfuric acid and dilute hydrochloric acid. This is because poorly soluble substances represented by [B] in dilute sulfuric acid and [C] in dilute hydrochloric acid are formed on the surface of the element.

Grand Challenge

Electronic waste contains aluminium, zinc, copper, gold and other valuable metals.
Your challenge: Design a chemical process that separates aluminium from other metals using its amphoteric behaviour.
Consider:
- Which reagent would you use?.....
- Why would aluminium dissolve while another metal remains?.....
- How could this improve recycling?.....

Be Global Citizen

Electrochemical cells play a major role in sustainable development. Where it uses in Electric vehicles, Renewable energy storage, Portable medical devices, Emergency power systems, Satellite technologies

Advances in battery technology can reduce fossil fuel dependence and support global sustainability goals.

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Exercise

1.Aluminium hydroxide is treated with excess sodium hydroxide.

Which ion is produced?

A. Al^{3+}

B. Al_2O_3

C. $[Al(OH)_4]^-$

D. $AlCl_3$

.....

2.A white precipitate disappears after excess ammonia is added to a zinc ion solution.

Which complex ion is formed?

A. $[Zn(OH)_4]^{2-}$

B. $[Zn(NH_3)_4]^{2+}$

C. $ZnCl_2$

D. ZnO

.....

3. Read the following text and answer the questions below.

Aluminium is manufactured by (A) electrolysis of the oxide obtained from the ore (B), and is an (C) metal that dissolves in aqueous solutions of both acids and strong bases, generating hydrogen. When a small amount of aqueous sodium hydroxide solution is added to an aqueous solution containing Al^{3+}, (I) a white precipitate is formed, but when added in excess, this precipitate dissolves to form a (II) colourless solution.

(a) Identify the appropriate terms for (A) through (C).

(b) Write the chemical equations for the following reactions:

(i) Reaction of aluminium with dilute hydrochloric acid

(ii) Reaction of aluminium with aqueous sodium hydroxide solution

(c) Write the chemical formula of the substance in the underlined part (I).

(d) Write the chemical formula of the anion contained in the solution of the underlined part (II).

4. Identify the appropriate terms or numbers for (i) and (iii), and the chemical formulas for (ii), (iv), and (v) to complete the following passage.

Zinc is an element belonging to Group (i) of the periodic table. When zinc is burned in the air, it produces (ii).

The element is an (iii) metal, and dissolves in both hydrochloric acid and aqueous sodium hydroxide to generate hydrogen. When aqueous ammonia is added to an aqueous solution containing zinc ions, a white precipitate of (iv) is produced. Furthermore, when aqueous ammonia is added, the precipitate dissolves, and a complex ion (v) is produced.

5. Which two of the following statements (A to D) about tin and lead are incorrect?

A. Tin(II) chloride acts as a reducing agent.

B. Lead(II) sulfate is easily soluble in dilute sulfuric acid.

C. Lead(IV) oxide is used as an oxidising agent.

D. Tin and lead are both transition elements.

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Lesson 3-9 — Transition Elements and Their Compounds (1) (Iron, Copper, Silver)

Engaging Introduction

Imagine you accidentally leave a bicycle outside for several weeks. The shiny metal slowly turns reddish-brown as rust forms. In another place, a laboratory technician adds a few drops of different solutions into an unknown sample. Within seconds, the solution changes colour, allowing the technician to identify which metal ion is present.

Although iron, copper, and silver are all metals, each behaves differently because of its electron arrangement and chemical properties.

In this lesson, you will explore how chemists use colour changes, precipitates, and complex ions to identify transition metals and explain why these metals are important in engineering, medicine, and environmental science.

Guiding Question Why do different transition metal ions produce different colours and reactions?

Exploration

Look at these everyday observations.

• An old iron gate develops reddish-brown rust.

• Copper roofs slowly become green after many years.

• Old silver jewelry sometimes becomes black.

Without studying the lesson,

Why do different metals change into different colours?

.....

Why doesn't every metal rust in the same way?

.....

How could a chemist identify these metals if they were dissolved in water?

.....

Point!

1. Iron Fe

(a) Iron ions: Iron ions include the iron(II) ion Fe^{2+} and the iron(III) ion Fe^{3+}.

• When Fe^{2+} is oxidised, it becomes Fe^{3+} .

(b) Reactions of iron ions in aqueous solutions: Reactions differ between Fe^{2+} and Fe^{3+}.

Structure of Science

Key fact :

Transition metals can often be identified because they form distinctive coloured ions, precipitates, and complex ions during chemical reactions.

Key Concepts

• Transition elements

• Oxidation and reduction Coordination bonding

• Qualitative analysis

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⟨Aqueous solution added and colour change⟩

Aqueous solution added	$NaOH$, NH_3	H_2S	$K_4[Fe(CN)_6]$	$K_3[Fe(CN)_6]$	KSCN
Aqueous solution containing Fe^{2+}	**Greenish-white** precipitate	Black precipitate	Bluish-white precipitate	**Dark blue** precipitate	No change
Aqueous solution containing Fe^{3+}	**Reddish-brown** precipitate	Black precipitate	**Dark blue** precipitate	Brown solution	**Blood-red** solution

• When aqueous sodium hydroxide NaOH or aqueous ammonia NH_3 is added:

In an aqueous solution containing Fe^{2+}, a precipitate of **iron(II) hydroxide $Fe(OH)_2$** is produced.

$$Fe^{2+} + 2OH^- \longrightarrow Fe(OH)_2$$

In an aqueous solution containing **iron(III) hydroxide** is produced.

Iron(III) hydroxide cannot be represented by a single chemical formula.

Predict

Without performing the experiment, predict what will happen.

A chemist adds sodium hydroxide solution separately to:

• Fe^{2+} solution

• Fe^{3+} solution

• Cu^{2+} solution

• Ag^+ solution

Complete the table.

Metal ion	Prediction
Fe^{2+}	_____
Fe^{3+}	_____
Cu^{2+}	_____
Ag^+	_____

2. Copper Cu

(a) Reactions of copper Cu

• Heating copper in air produces black **copper(II) oxide (CuO)** .

• Dissolving copper in hot concentrated sulfuric acid produces **copper(II) sulfate ($CuSO_4$)** .

(b) Reactions of copper(II) ion Cu^{2+}

• Addition of an aqueous base produces a bluish-white precipitate of **copper(II) hydroxide ($Cu(OH)_2$)** .

$$Cu^{2+} + 2OH^- \longrightarrow Cu(OH)_2$$

• Passing hydrogen sulfide through the solution produces a **black** precipitate of **copper(II) sulfide (CuS)** .

(c) Reactions of copper(II) hydroxide $Cu(OH)_2$

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• Adding excess aqueous ammonia: tetraamminecopper(II) ions **$[Cu(NH_3)_4]^{2+}$** form, resulting in a **deep blue** aqueous solution.

$$Cu(OH)_2 + 4NH_3 \longrightarrow [Cu(NH_3)_4]^{2+} + 2OH^-$$

• Heating: $Cu(OH)_2$ decomposes to produce black **copper(II) oxide (CuO)** .

• Dissolving in dilute sulfuric acid or hydrochloric acid: Copper(II) ions Cu^{2+} form.

Think as an Engineer

Engineers designing water distribution systems must choose pipe materials carefully. Copper pipes are commonly used because they resist corrosion better than iron.

Question

Why would copper be a better material than iron for drinking-water pipes?

Consider:

• corrosion
• durability
• water quality
• maintenance costs

.....

3. Silver Ag

(a) Reactions of silver ion Ag^+

• Adding an aqueous base solution: A **brown** precipitate of **silver oxide Ag_2O** forms.

$$2Ag^+ + 2OH^- \longrightarrow Ag_2O + H_2O$$

• Further adding aqueous ammonia: diamminesilver(I) ions **$[Ag(NH_3)_2]^+$** form, resulting in a colourless aqueous solution.

$$Ag_2O + 4NH_3 + H_2O \longrightarrow 2[Ag(NH_3)_2]^+ + 2OH^-$$

• Passing hydrogen sulfide through: A **black** precipitate of **silver sulfide (Ag_2S)** forms.

$$2Ag^+ + S^{2-} \longrightarrow Ag_2S$$

(b) Silver halides: Compounds of silver and halogens (Cl, Br, I). Formed by the reaction of silver ions and halide ions. (Table 3-9-1 on the right)

Table 3-9-1 <Colours of Silver Halides>

Name	Chemical formula	Colour
Silver chloride	AgCl	White
Silver bromide	AgBr	Light yellow
Silver iodide	AgI	Yellow

• When silver halides are exposed to light, they decompose to yield silver metal.

Example: $2AgBr \xrightarrow{Light} 2Ag + Br_2$

Life application

Silver compounds have been used for over a century in photography.
When silver bromide is exposed to light, it decomposes to produce metallic silver.
Although digital cameras have largely replaced photographic film, this light-sensitive reaction remains an important example of photochemistry and is still used in specialized imaging technologies.

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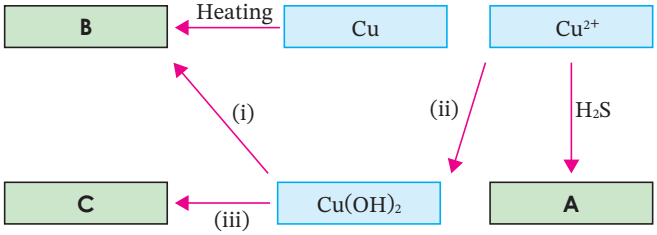
Warm Up

Answer the following questions.

(a) Identify the appropriate chemical formulas for (A), (B), and (C) in the following passage.

When dilute sulfuric acid is added to iron, it dissolves while generating hydrogen, producing a cation represented by
(A). This ion is oxidised by hydrogen peroxide to become an ion represented by (B). The formation of (B) can be confirmed by the fact that the aqueous solution turns blood-red when an aqueous solution of (C) is added to it.

(b) Answer the following questions based on the figure showing the reactions of copper and its compounds.



(I) Identify the chemical formulas for substances A, B, and C. Note that C is a complex ion.

(II) Select the most appropriate reagent or procedure for (i) through (iii) from the options below. Each option can be used only once.

a. Heating b. O_2 c. H_2 d. NH_3 e. NaOH

Explanation

(a) A: Fe^{2+} B: Fe^{3+} C: KSCN

(b) (I) A: When hydrogen sulfide is passed through an aqueous solution containing copper(II) ions, a precipitate of copper(II) sulfide is produced. Answer: CuS

B: Heating copper produces copper(II) oxide. Answer: CuO

C: The complex ion produced by the reaction with copper(II) hydroxide is the tetraamminecopper(II) ion. Answer: $[Cu(NH_3)_4]^{2+}$

(II) (i): Heating copper(II) hydroxide produces copper(II) oxide.

(ii): Adding an aqueous base solution to an aqueous solution containing copper(II) ions produces a precipitate of copper(II) hydroxide.

(iii): Adding excess aqueous ammonia to copper(II) hydroxide produces tetraamminecopper(II) ions.

Therefore, since aqueous ammonia NH_3 corresponds to (iii), NaOH, which is the remaining aqueous base solution, corresponds to (ii).

From the above, (i): a (ii): e (iii): d

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Try

Choose the correct answer:

1-A pale green solution is suspected to contain Fe^{2+} ions. A student adds sodium hydroxide solution. Which observation is most likely?

A. A greenish-white precipitate

B . A deep blue solution

C. A brown solution

D. No visible change

.....

2. A solution gives a blood-red colour after adding potassium thiocyanate (KSCN).

Which ion is present?

A. Fe^{2+}

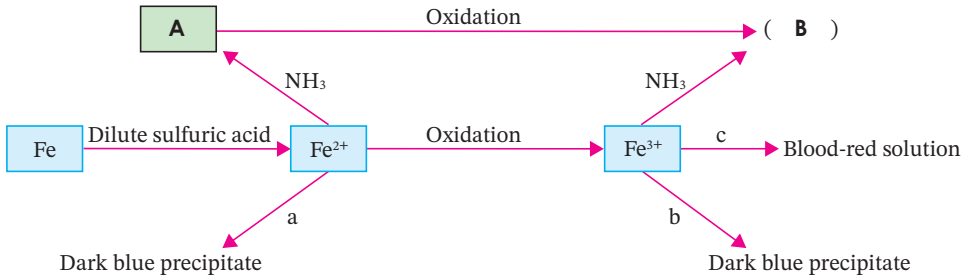
B. Fe^{3+}

C. Cu^{2+}

D. Ag^{+}

.....

3. Answer the following questions based on the diagram showing the reactions of iron and its compounds.



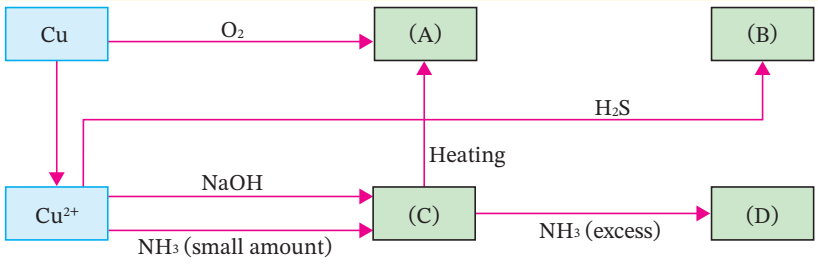
(a) Identify the chemical formula and colour for substance A.

(b) Identify the colour for substance B.

(c) Select the appropriate reagent for steps a, b, and c from the list (i) through (v).

(i) KCl (ii) KSCN (iii) NaOH (iv) $K_3[Fe(CN)_6]$ (v) $K_4[Fe(CN)_6]$

4.Answer the questions below regarding the following diagram.



(a) Identify the chemical formulas for compounds (A) through (C).

(bIdentify the name and chemical formula for the complex ion present in solution (D).

3. Identify the chemical formulas and colours for substances A, B, and C based on the following experiments.

Experiment I: When an aqueous sodium chloride solution was added to an aqueous

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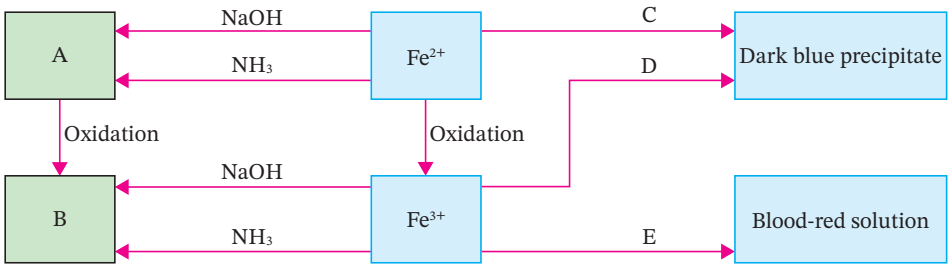
silver nitrate solution, precipitate A was produced.

Experiment II: When precipitate A was exposed to light, it decomposed to produce fine particles of B.

Experiment III: When excess aqueous ammonia was added to precipitate A, complex ion C was produced.

Exercise

1. Answer the following questions based on the diagram showing the reactions of iron and its compounds.



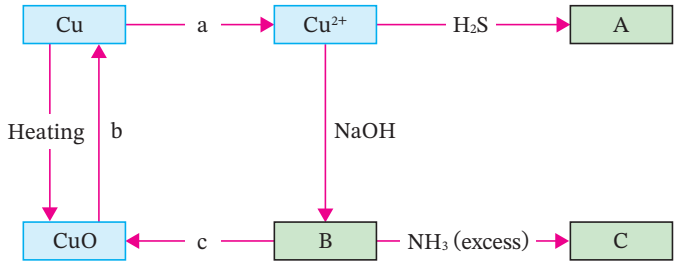
(a) Provide the chemical formula and colour for precipitate A.

(b) Provide the name and colour for precipitate B.

(c) Select the appropriate reagent for steps C, D, and E from the following options (i) to (iv).

(i) KSCN (ii) $K_4[Fe(CN)_6]$ (iii) KCl (iv) $K_3[Fe(CN)_6]$

2. The reactions of copper and its compounds are shown in the following diagram. Answer the questions below.



(a) Identify the chemical formulas for substances A, B, and C. Note that C is a complex ion

(b) Select the appropriate reagent or operation for steps a, b, and c from the following options (i) to (v).

(i) H_2 (ii) O_2 (iii) HCl (iv) HNO_3 (v) Heating

3. When aqueous sodium hydroxide, dilute hydrochloric acid, aqueous potassium bromide, and aqueous hydrogen sulfide were added to an aqueous silver nitrate solution, precipitates A, B, C, and D were produced, respectively. Identify the chemical formulas and colours for precipitates A, B, C, and D.

Challenge Your Thinking

A forensic scientist finds a colourless solution that may contain chloride ions.
After adding silver nitrate, a white precipitate appears.
Later, the precipitate darkens after being exposed to sunlight.
Questions
Which silver compound was probably formed? .....
Why did its colour change after exposure to light? .....
What property of silver halides makes them useful in photography? .....

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Lesson 3-10 — Transition Elements and Their Compounds (2) (Gold, Chromium, Manganese)

Engaging Introduction

Gold has fascinated people for thousands of years. From the treasures of ancient Egypt, including Tutankhamun's golden mask, to the tiny electrical connectors inside today's smartphones and computers, gold remains one of the world's most valuable materials. Meanwhile, brightly coloured chromium and manganese compounds are widely used in laboratories, environmental testing, and water treatment because their colour changes reveal important chemical reactions.

Let's explore how the unique properties of gold, chromium, and manganese make them essential in modern technology, chemical analysis, and everyday life.

Guiding Question How do chemists use colour changes and chemical reactions to identify substances and explain their behaviour?

Structure of Science

Key fact :

Many transition-metal compounds undergo predictable colour changes because their oxidation states change during chemical reactions.

Key concepts:

Noble metals – Oxidation- Chemical equilibrium - Oxidising agents Transition elements

Exploration

Before studying the lesson,

Why doesn't gold rust like iron?

.....

Why are chromium compounds used in the bright yellow pigments of traffic signs?

.....

Point!

Egypt, where you live, has a deep connection with gold dating back to ancient times. Beginning with Tutankhamun's golden mask, which retains its brilliance after thousands of years, what special properties does gold possess?

1. Gold (Au)

Discovery and Physical Properties

Gold (Au) is found in its **elemental state**, uncombined with other elements, such as in alluvial gold (gold dust).

- **Malleability and Ductility**: It possesses the highest **malleability** (the property of being spread into thin sheets) and **ductility** (the property of being drawn into fine wires) among all metals. Due to this extremely high workability, it is widely utilized, from ancient ornaments to modern nanotechnology.
- **Conductivity**: It is an excellent **conductor** of electricity and heat.
- **Luster and Applications**: It has a beautiful golden **luster** and is highly resistant to oxidation (i.e., it does not rust), **making it extremely useful**. Because of these superior properties, gold is an indispensable metal for accessories and ornaments,

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as well as a material for precise electronic devices such as mobile phones and computers.

Chemical Stability (Noble Metal)

- Gold has very low **reactivity**, making it chemically stable. For this reason, it does not dissolve in very strong acids like **nitric acid** or hot **concentrated sulfuric acid**.
- However, it dissolves in a special mixture of concentrated nitric acid and concentrated hydrochloric acid called Aqua Regia . In Aqua Regia, gold is oxidised and forms a stable complex ion, which allows this mixture to dissolve gold, despite gold being one of the most stable metals.

2. Chromium Cr

(a) Chromium compounds

(i) Potassium chromate K_2CrO_4

- When dissolved in water, yellow chromate ions CrO_4^{2-} form.

(ii) Potassium dichromate $K_2Cr_2O_7$

- When dissolved in water, red-orange dichromate ions $Cr_2O_7^{2-}$ form.

NOS: Prediction

A yellow chromate solution is treated with dilute sulfuric acid.
Predict what will happen.
□ The colour remains yellow.
□ The solution turns orange.
□ A precipitate forms.
Explain your prediction.
……

(b) Chromate ion CrO_4^{2-} and Dichromate ion $Cr_2O_7^{2-}$

- Chromate ions react with silver ions Ag^+, lead(II) ions Pb^{2+}, and barium ions Ba^{2+} to produce coloured precipitates in all cases. (Table 3-10-1 on the right)

Table 3-10-1 ⟨Precipitates by chromate ions⟩

Name of precipitate	Colour of precipitate
Silver chromate Ag_2CrO_4	Reddish-brown
Lead(II) chromate $PbCrO_4$	Yellow
Barium chromate $BaCrO_4$	Yellow

- When an aqueous solution containing chromate ions is acidified, dichromate ions are produced. When the solution is made basic, they revert to chromate ions.

$$\underset{\text{(Yellow)}}{CrO_4^{2-}} \underset{OH^-}{\overset{H^+}{\rightleftharpoons}} \underset{\text{(Red-orange)}}{Cr_2O_7^{2-}}$$

- Dichromate ions act as a strong oxidising agent in acidic aqueous solutions, producing dark green chromium(III) ions Cr^{3+}.

Inquiry Investigation

Investigating Colour Changes in Chemical Equilibrium

Materials

- Potassium chromate solution
- Dilute sulfuric acid
- Sodium hydroxide solution
- Two test tubes
- Dropper

Procedure

1. Pour potassium chromate solution into a test tube.

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2. Add a few drops of dilute sulfuric acid.
3. Observe the colour.
4. Add sodium hydroxide solution.
5. Observe the colour again.

Observation ……

Conclusion……

3. Manganese Mn Compounds

(a) Manganese(IV) oxide MnO_2 ● Also called manganese dioxide.

- A black powder.
- Acts as an oxidising agent in acidic aqueous solutions, producing **pale pink** manganese(II) ions Mn^{2+}.

(b) Potassium permanganate $KMnO_4$

- Black-purple crystals.
- When dissolved in water, **red-purple** permanganate ions MnO_4^- form.
- Acts as a strong **oxidising** agent in acidic aqueous solutions, producing manganese(II) ions Mn^{2+}.

Warm Up

Choose one incorrect statement from the following descriptions.

A . When aqueous silver nitrate is added to an aqueous potassium chromate solution, a reddish-brown precipitate is produced.

B. When aqueous lead(II) acetate is added to an aqueous potassium chromate solution, a yellow precipitate is produced.

C. When a small amount of dilute sulfuric acid is added to an aqueous potassium chromate solution, the aqueous solution turns red-orange.

D. Manganese(IV) oxide is a black powder and reacts with concentrated hydrochloric acid to generate chlorine.

E Potassium permanganate dissolves in water to form a red-purple aqueous solution, and acts as a strong reducing agent in acidic aqueous solutions.

Explanation

A: Chromate ions CrO_4^{2-} are contained in the aqueous potassium chromate solution, and silver ions Ag^+ are contained in the aqueous silver nitrate solution. These ions react to produce a reddish-brown precipitate of silver chromate.

B: Lead(II) ions Pb^{2+} are contained in the aqueous lead(II) acetate solution. Chromate ions and lead(II) ions react to produce a yellow precipitate of lead(II) chromate $PbCrO_4$.

C: When dilute sulfuric acid is added to an aqueous potassium chromate solution, the aqueous solution becomes acidic. As a result, dichromate ions are produced, so the aqueous solution turns red-orange.

D: Manganese(IV) oxide, which is a black powder, acts as an oxidising agent in acidic aqueous solutions, so it produces chlorine Cl_2 as shown in the following chemical equation:

Be Global Citizen

Gold, chromium, and manganese are critical materials used worldwide.

Using these resources responsibly requires balancing technological development with environmental protection and recycling. Responsible use of Earth's mineral resources helps support a sustainable future.

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$MnO_2 + 4HCl \longrightarrow MnCl_2 + 2H_2O + Cl_2$

E: Potassium permanganate acts as a strong oxidising agent in acidic aqueous solutions.

Therefore, E.

Think as an Environmental Chemist

Industrial wastewater sometimes contains chromium compounds.

Why is monitoring chromium compounds important before releasing wastewater into rivers?

Think about:

- human health,
- ecosystems,
- drinking water.

……

Try

Which of the following statements (i to iv) about chromium and manganese are incorrect?

(i) Both chromium and manganese are transition elements.

(ii) When chromate ions and lead(II) ions react, a reddish-brown precipitate is produced.

(iii) Permanganate ions show a red-purple colour in aqueous solutions.

(iv) Permanganate ions are reduced by hydrogen peroxide in acidic aqueous solutions.

……

……

……

Challenge Your Thinking

Two colourless solutions are tested.

Solution A changes orange dichromate solution to green.

Solution B does not.

Which solution is more likely to contain a reducing agent? Explain.

……

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Exercise

Choose the correct answer:

1. A laboratory technician observes a purple solution becoming colourless during an experiment.

Which compound is most likely being used?

A. Potassium chromate

B. Potassium dichromate

C. Potassium permanganate

D. Silver nitrate

.....

2. During a redox reaction, orange dichromate ions become green chromium(III) ions.

This colour change indicates that dichromate ions have:

A. gained electrons.

B. lost electrons.

C. evaporated.

D. become gases.

.....

3. Read the following text and answer the questions below.

In acidic aqueous solutions, both potassium dichromate ($K_2Cr_2O_7$, a chromium compound) and potassium permanganate ($KMnO_4$, a manganese compound) act as strong (I) agents. When $\underset{(A)}{\text{aqueous sodium hydroxide was added to an aqueous potassium dichromate solution}}$, and then $\underset{(B)}{\text{aqueous barium nitrate was added, a precipitate was produced.}}$

(a) Identify the appropriate term for blank (I).

(b) Describe the colour change of the aqueous solution that occurs in step (A).

(c) Write the net ionic equation for the reaction occurring in step (A).

(d) Identify the chemical formula and colour of the precipitate formed in step (B).

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Lesson 3-11 — Precipitation Reactions and Separation of Metal Ions

Engaging Introduction

A drinking water laboratory receives a water sample that may contain several dissolved metal ions. Although the solution looks perfectly clear, chemists can identify and separate each metal ion by adding carefully selected reagents. Suddenly, white, black, yellow, and reddish-brown precipitates appear one after another.

In this lesson, you will discover how chemists use precipitation reactions as a scientific tool to identify unknown substances and separate metal ions in environmental, industrial, and medical laboratories.

Guiding Question How can invisible dissolved metal ions be identified and separated using observable chemical reactions?

Exploration

Imagine two clear solutions are mixed together.

Within seconds, a bright yellow solid appears.

Without studying the lesson yet:

Why did a solid suddenly form although both solutions were transparent?

.....

What information might the colour of the precipitate provide?

.....

Point!

Precipitation reactions and separation of metal ions

(a) Precipitation reactions

Chemical formulas and colours of precipitates formed by various metal ions and anions (× indicates no precipitate is formed).

Anion / Metal ion	Cl^-	S^{2-} [Acidic]	S^{2-} [Basic]	OH^-
Ag^+	AgCl White	Ag_2S Black	Ag_2S (Black)	Ag_2O Brown
Pb^{2+}	$PbCl_2$ White	PbS Black	PbS (Black)	$Pb(OH)_2$ White
Cu^{2+}	×	CuS Black	CuS (Black)	$Cu(OH)_2$ Bluish-white
Fe^{2+}	×	×	FeS (Black)	$Fe(OH)_2$ Greenish-white
Fe^{3+}	×	×	FeS (Black)	Iron(III) hydroxide Reddish-brown

Structure of Science

Key fact :

- Different metal ions produce precipitates with characteristic colours when they react with specific anions.
- Chloride ions form white precipitates with Ag^+ and Pb^{2+}.
- Sulfide ions form black precipitates with Cu^{2+}, Fe^{2+}, and Fe^{3+}, and white precipitates with Zn^{2+}.

Key Concepts:

Selective Precipitation-Complex Ion Formation-Solubility -Complex IonsCondensation

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Al^{3+}	×	×	$Al(OH)_3$ (White)	$Al(OH)_3$ White
Zn^{2+}	×	×	ZnS White	$Zn(OH)_2$ White

(b) Precipitation reactions with other anions

(i) Reaction with chromate ion CrO_4^{2-}

• Ag^+ produces a reddish-brown precipitate of silver chromate Ag_2CrO_4 .

• Pb^{2+} produces a yellow precipitate of lead(II) chromate $PbCrO_4$.

(ii) Reaction with hexacyanidoferrate(II) ion $[Fe(CN)_6]^{4-}$

• Reacts with Fe^{3+} to produce a dark blue precipitate.

NOS: Prediction

Predict what will happen when:

• Silver nitrate is added to a chloride solution.

Prediction: .....

What evidence would confirm your prediction? .....

(c) Properties of precipitates

(i) Chloride precipitates

Between AgCl and $PbCl_2$,

• $PbCl_2$ is soluble in hot water.

• AgCl dissolves in excess aqueous ammonia, producing diamminesilver(I) ions $[Ag(NH_3)_2]^+$.

(ii) Hydroxide precipitates

Among Ag_2O, $Pb(OH)_2$, $Cu(OH)_2$, $Fe(OH)_2$, iron(III) hydroxide, $Al(OH)_3$, and $Zn(OH)_2$:

• Soluble in excess aqueous sodium hydroxide: $Pb(OH)_2$, $Al(OH)_3$, $Zn(OH)_2$

• Soluble in excess aqueous ammonia: Ag_2O, $Cu(OH)_2$, $Zn(OH)_2$

(d) Separation of metal ions: By utilizing precipitation reactions of metal ions, specific metal ions can be separated from an aqueous solution containing multiple metal ions.

Table 3-11-1 ⟨Procedures and precipitates for separation of metal ions⟩

Operation	Precipitating metal ions	Precipitate (Colour)
❶ Add dilute hydrochloric acid	Ag^+ , Pb^{2+}	AgCl (White), $PbCl_2$ (White)
❷ Pass hydrogen sulfide gas through the solution	Cu^{2+} , Cd^{2+}	CuS (Black), CdS (Yellow)
❸ Add excess aqueous ammonia	Fe^{3+} , Al^{3+}	Iron(III) hydroxide (Reddish-brown), $Al(OH)_3$ (White)
❹ Pass hydrogen sulfide gas through the solution	Zn^{2+} , Mn^{2+}	ZnS (White), MnS (Pale-pink)
❺ Add aqueous ammonium carbonate	Ca^{2+} , Ba^{2+}	$CaCO_3$ (White), $BaCO_3$ (White)

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Think Critically

Claim

A white precipitate alone is not enough to identify a metal ion.

Evidence

$AgCl$, $PbCl_2$, $Al(OH)_3$ and $Zn(OH)_2$ can all appear white.

Reasoning

Use information from this lesson to explain why additional chemical tests are necessary before identifying an unknown ion.

.....

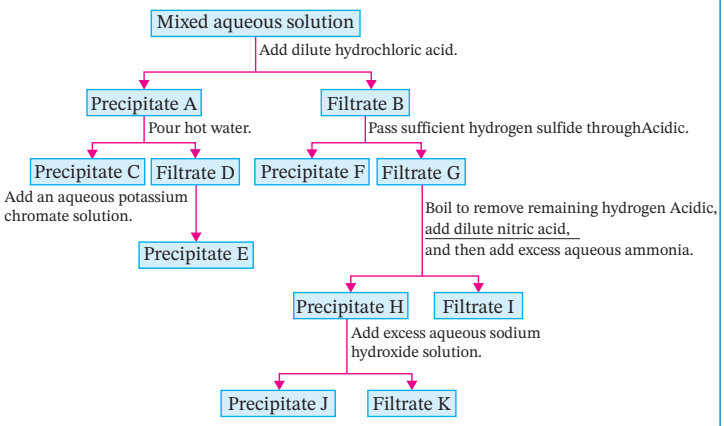
.....

Warm Up

Based on the flowchart showing the separation of six metal ions (Ag^+, Al^{3+}, Cu^{2+}, Fe^{3+}, Pb^{2+}, and Zn^{2+}) from a mixed aqueous solution, answer the following questions.

(a) Identify the chemical formulas and colours for precipitates C, E, and F. Identify the name and colour for precipitate J.

(b) Identify the chemical formulas for the complex ions formed when the metal ions in precipitate C and filtrate I react with ammonia.



(c) Explain the purpose of the underlined operation in the flowchart.

(d) Explain the problem that would occur if hydrogen sulfide (H_2S) gas were mistakenly passed through the mixed aqueous solution before the addition of dilute hydrochloric acid (HCl).

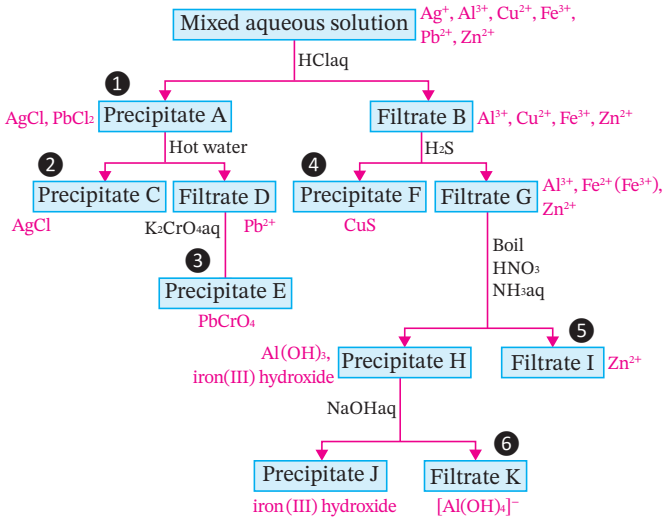
Explanation

Confirm the reactions one by one.

❶ When dilute hydrochloric acid is added, the ions that produce precipitates are Ag^+ and Pb^{2+}, and the chemical formulas of the precipitates are AgCl and $PbCl_2$.

❷ Of ❶, the one that does not dissolve in hot water is AgCl.

❸ When an aqueous potassium chromate solution is added to the aqueous solution in which $PbCl_2$ is dissolved in hot water, Pb^{2+} and chromate ions CrO_4^{2-} in the aqueous solution react to



Sustainability Connection

Many electronic devices contain valuable metals such as silver and copper.

Instead of mining new metals, industries can recover these metals from electronic waste using precipitation reactions.

Recovering metals helps to:

- reduce mining waste
- conserve natural resources
- decrease environmental pollution
- support a circular economy

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produce a yellow precipitate of lead(II) chromate $PbCrO_4$.

❹ The ions contained in filtrate B are Al^{3+}, Cu^{2+}, Fe^{3+}, and Zn^{2+}. Also, because dilute hydrochloric acid was added in ⓧ, the aqueous solution is acidic. At this time, when hydrogen sulfide is passed through, it is Cu^{2+} that produces a precipitate, and the chemical formula of the precipitate is CuS.

❺ The ions contained in filtrate G are Al^{3+}, Fe^{2+} (Fe^{3+}), and Zn^{2+}. When an aqueous base solution is added to these, they produce precipitates of $Al(OH)_3$, iron(III) hydroxide, and $Zn(OH)_2$, respectively. Of these, the one that dissolves in excess aqueous ammonia is $Zn(OH)_2$.

❻ $Al(OH)_3$ dissolves in excess aqueous sodium hydroxide, whereas iron(III) hydroxide does not.

(a) C Chemical formula: AgCl, Colour: White E Chemical formula: $PbCrO_4$, Colour: Yellow F Chemical formula: CuS, Colour: Black J Substance name: Iron(III) hydroxide, Colour: Reddish-brown

(b) C: Since the ion contained in precipitate C is Ag^+, the complex ion formed with ammonia is $[Ag(NH_3)_2]^+$.
I: Since the ion contained in filtrate I is Zn^{2+}, the complex ion formed with ammonia is $[Zn(NH_3)_4]^{2+}$.

(c) By the hydrogen sulfide added in ❹, Fe^{3+} has been reduced to Fe^{2+}. To oxidise it back to Fe^{3+}, dilute nitric acid is added. **Example:** To oxidise Fe^{2+} back to Fe^{3+}.

(d) Ag^+ and Pb^{2+} would precipitate prematurely as sulfides, preventing their separation from metal ions such as Cu^{2+}. Consequently, subsequent analytical procedures—such as the dissolution of Pb^{2+} in hot water and its detection using chromate (CrO_4^{2-})—would be rendered impossible.

Think as an Engineer

Chemical engineers often design automated systems that continuously separate dissolved metal ions during water treatment and mining.
Which property of precipitates would be most important when designing such a system? Explain your answer.
……

Try

Choose the correct answer:

1. Which property makes Zn^{2+} different from Fe^{3+} during separation?

A. $Zn(OH)_2$ dissolves in excess ammonia

B. Zn^{2+} forms a red precipitate.

C. Fe^{3+} dissolves in ammonia.

D. Fe^{3+} forms no precipitate.

……

……

2. A white precipitate forms after adding dilute hydrochloric acid. Why is hot water added next?

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A. To dissolve AgCl.

B. To dissolve $PbCl_2$.

C. To dissolve CuS.

D. To remove Zn^{2+}.

.....

3. For each of the following questions, identify the appropriate metal ions from the given list (A to G).

(A) Ag^+ (B) Cu^{2+} (C) Fe^{3+} (D) Fe^{2+}

(E) Al^{3+} (F) Pb^{2+} (G) Zn^{2+}

(a) Which of the metal ions produce a precipitate when dilute hydrochloric acid is added? (Select all that apply.)

(b) Choose all metal ions that produce a precipitate when a small amount of aqueous sodium hydroxide is added, and answer with their letters.

(c) From the precipitates formed in **(b)**, choose all that dissolve when an excess of aqueous sodium hydroxide is added, and answer with their letters.

(d) From the precipitates formed in **(b)**, choose all that dissolve when an excess of aqueous ammonia is added, and answer with their letters.

4. Which of the following ions (A to G) exhibits the reactions described in **(a)** through **(e)**?

(a) When aqueous ammonia is added, a bluish-white precipitate is produced, but when aqueous ammonia is further added, the precipitate dissolves to form a deep blue aqueous solution.

(b) When dilute hydrochloric acid is added, a white precipitate is produced. When this precipitate is exposed to light, it turns black.

(c) When aqueous ammonia is added, a white precipitate is produced, but when aqueous ammonia is further added, the precipitate dissolves to form a colourless aqueous solution.

(d) When an aqueous potassium hexacyanidoferrate(II) solution is added, a dark blue precipitate is produced.

(e) When hydrochloric acid is added, a white precipitate is produced, and when an aqueous potassium chromate solution is added, a yellow precipitate is produced.

(A) Ag^+ **(B)** Al^{3+} **(C)** Cu^{2+} **(D)** Fe^{2+} **(E)** Fe^{3+} **(F)** Pb^{2+} **(G)** Zn^{2+}

5. The operations (i) to (v) in the following figure were performed on a mixed solution containing six metal ions: K^+, Ag^+, Ca^{2+}, Zn^{2+}, Cu^{2+}, and Al^{3+}.

Write the chemical formulas for the precipitates formed at each step (a) to (e) and for the ions present in the final filtrate (f).

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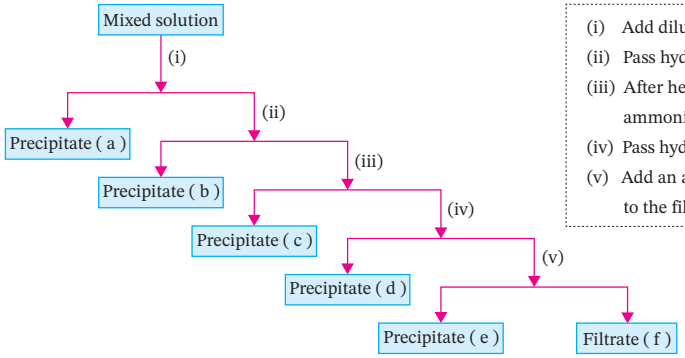

(i) Add dilute hydrochloric acid
(ii) Pass hydrogen sulfide gas through the Acidic
(iii) After heating the filtrate, add excess aqueous ammonia to make it basic
(iv) Pass hydrogen sulfide gas through Basic
(v) Add an aqueous ammonium carbonate solution to the filtrate

Exercise

1. Complete the following table by identifying the chemical formula and colour of the precipitate formed when each metal ion reacts with the specified reagent. If no precipitate forms, write ×.

	Ag^+	Pb^{2+}	Cu^{2+}	Al^{3+}	Zn^{2+}
Hydrochloric acid	AgCl, White	A	B	C	×
Hydrogen sulfide (Acidic)	D	E	F	×	G
Aqueous ammonia (small amount)	H	I	$Cu(OH)_2$, Bluish-white	$Al(OH)_3$, White	J
NaOH aqueous solution (small amount)	K	$Pb(OH)_2$, White	L	M	N

2. Identify the cation (from A to H) that corresponds to each of the following observations **(a)** through **(e)**.

(a) When a small amount of aqueous ammonia is added, a bluish-white precipitate is produced, and when an excess of aqueous ammonia is added, the precipitate dissolves to form a deep blue aqueous solution.

(b) When hydrochloric acid is added, a white precipitate is obtained, and when an aqueous potassium chromate solution is added, a reddish-brown precipitate is obtained.

(c) When an aqueous potassium hexacyanidoferrate(II) solution is added, a dark blue precipitate is produced.

(d) When a small amount of aqueous ammonia is added, a white precipitate is produced. Even if excess aqueous ammonia is added to this precipitate, it does not dissolve, but if excess aqueous sodium hydroxide is added, the precipitate dissolves.

(e) Produces a red-purple flame in a flame test.

(A) Ag^+ **(B)** Cu^{2+} **(C)** Fe^{3+} **(D)** Al^{3+}

(E) Zn^{2+} **(F)** Ba^{2+} **(G)** Na^+ **(H)** K^+

3. A solution contains eight metal ions: Pb^{2+}, Cu^{2+}, Fe^{3+}, Zn^{2+}, Ba^{2+}, K^+, Ag^+, and Al^{3+}. A series of operations shown in the diagram were performed to separate and identify each ion. Answer the following questions.

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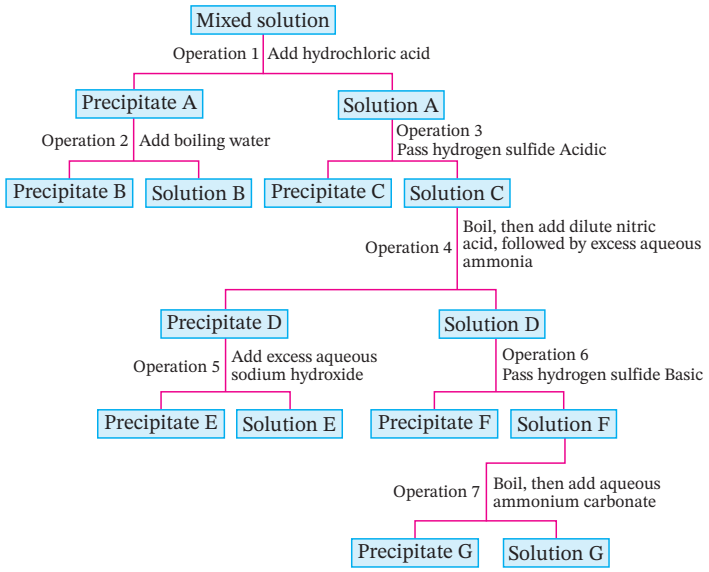

(a) Identify the name and chemical formula of precipitate B.

(b) Explain why dilute nitric acid is added in operation 4.

(c) Write the chemical formula of the complex ion present in solution E.

(d) From the initial eight metal ions, identify which ions are present in solution G. Write their chemical formula.

Challenge Your Thinking

A solution contains the following ions:

- Ag^{+}
- Pb^{2+}
- Cu^{2+}
- Zn^{2+}

Design the shortest possible sequence of reagents that separates all four ions.
Justify every step using the chemistry you learned.

.....

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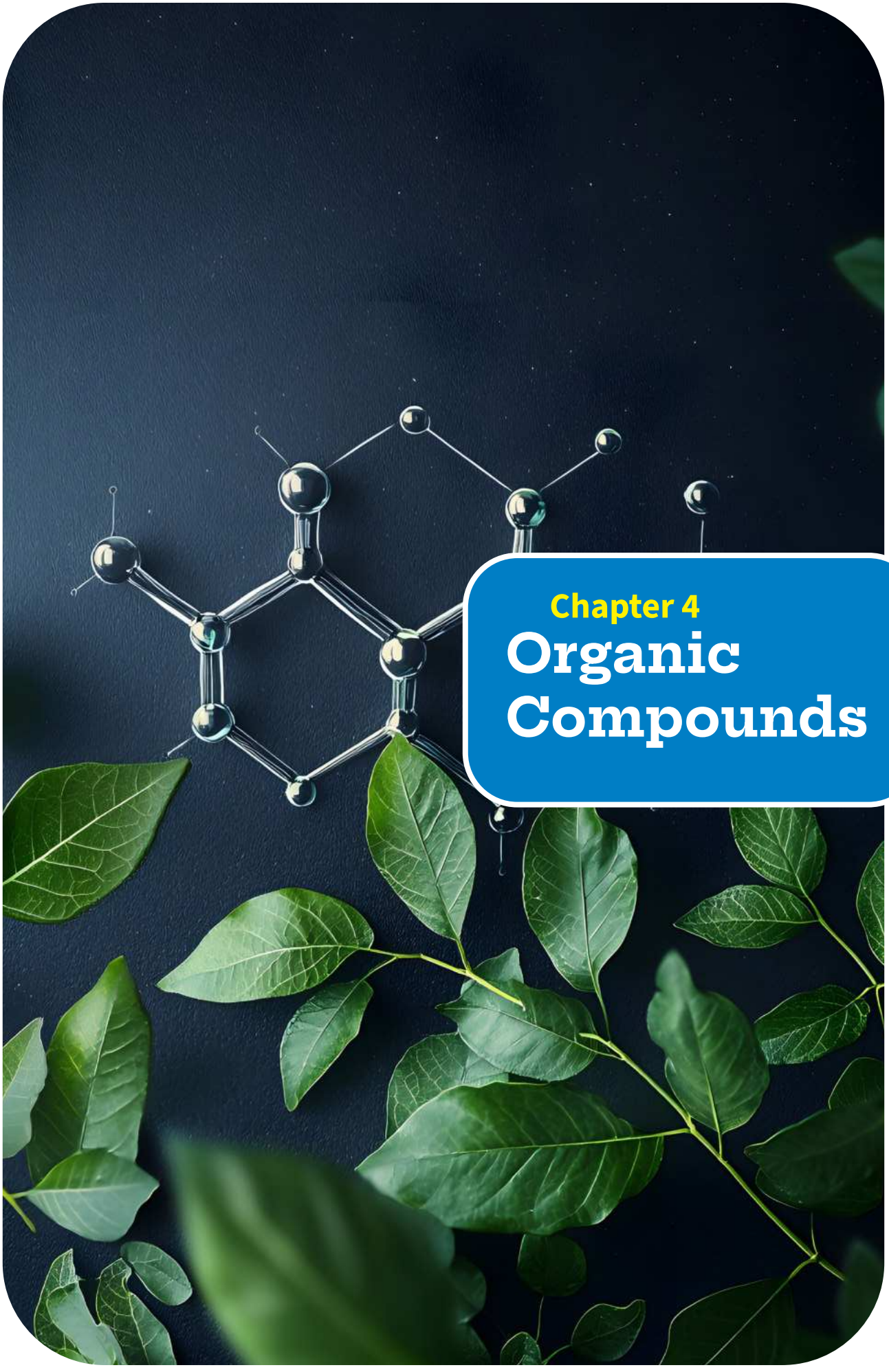

Chapter 4

Organic Compounds

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Lesson 4-1 — Covalent Bonds

Engaging Introduction

Imagine watching two invisible gases—hydrogen and oxygen. Individually, hydrogen is highly flammable, while oxygen supports combustion. Yet when they react together, they form water, a liquid that can extinguish fire.

Every breath you take, every drop of water you drink, every molecule in your body exists because atoms share electrons in a remarkable way.

Today, you will discover how chemists explain the invisible connections that hold matter together.

Guiding Question How does the sharing of electrons allow atoms to form stable molecules with properties that are completely different from the individual atoms?

Exploration

A chemistry student builds four molecular models.

Hydrogen forms one bond.

Oxygen forms two bonds.

Nitrogen forms three bonds.

Carbon forms four bonds.

Observation

Describe the relationship between the number of unpaired electrons and the number of bonds formed.

……

Inference

Why do different elements form different numbers of covalent bonds?

Use electron arrangements to justify your answer.

……

Structure of Science

Key Fact :

- Covalent bonds form by sharing electrons.
- Molecules consist of atoms joined by covalent bonds.
- Shared electron pairs form covalent bonds.
- Lone pairs do not participate in bonding. where complex ions form via coordinate bonds donated from ligand lone pairs.

Key Concepts:

covalent bond- lone pairs - bonding pairs- structural formulas

Point!

1. Covalent Bonds

(a) **Covalent bond**: A bond formed by the sharing of valence electrons between atoms.

(b) **Molecule**: A It consists from Two or more atoms joined by covalent bond or more atoms joined by covalent bonds.

2. Lewis Structures (Electron Dot Diagrams)

(a) **Lewis symbol of atoms** : A notation in which dots are placed around an element's symbol to represent its valence electrons.

- Among the valence electrons, two electrons that are paired together are called a lone pair (**electron pair**), and a single electron that is not paired with another electron is called an **unpaired electron**.

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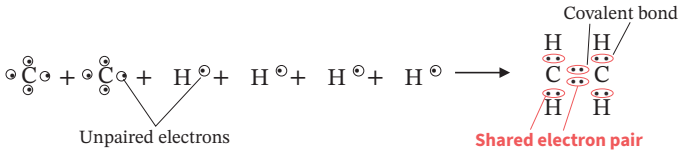
Group	1	2	13	14	15	16	17	18
Lewis symbol	Li ·	· Be ·	· $\dot{B}$ ·	· $\dot{C}$ ·	· $\ddot{N}$ ·	: $\ddot{O}$ ·	: $\ddot{F}$ ·	: $\ddot{Ne}$:
Number of unpaired electrons	1	2	3	4	3	2	1	0

(b) Lewis structures of molecules

- A covalent bond is formed when an unpaired electron of an atom pairs with an unpaired electron of another atom. An electron pair shared between atoms in this way to form a covalent bond is called a **shared electron pair** (bonding pair). An electron pair not shared between atoms is called a lone pair of electrons (lone pair).

Example: C_2H_4 (Ethylene) molecule



- A covalent bond formed by sharing one electron pair is called a **single bond**. Covalent bonds formed by sharing two or three electron pairs are called **double bonds** and **triple bonds**, respectively.

2. Structural Formulas

(a) **Structural formula**: A chemical formula representing covalent bonds within a molecule using lines (bonds).

(b) Lewis structures and structural formulas of major molecules

Name and molecular formula	Lewis structure	Structural formula
Hydrogen H_2	H : H	H — H
Water H_2O	H : $\ddot{O}$: H	H — O — H
Ammonia NH_3	H : $\ddot{N}$: H H	H — N — H | H
Methane CH_4	H H : $\dot{C}$: H H	H | H — C — H | H

A structural formula can be drawn by replacing one pair of shared electrons in Lewis structure with one line.

Life Application

DNA Structure

Every DNA molecule is held together by millions of covalent bonds linking atoms into long chains. Without covalent bonds, genetic information could not be stored.

Food Chemistry

Proteins, carbohydrates, and fats all consist of atoms connected through covalent bonds. Breaking and forming these bonds releases energy during metabolism.

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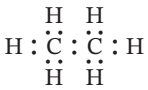
Warm Up

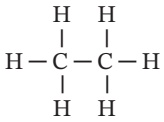
Write the Lewis structure and structural formula for each of the following molecules.

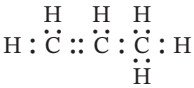
(i) C_2H_6 (ii) C_3H_6 (iii) HCl

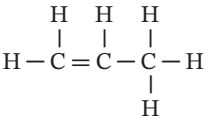
Explanation

Remember to include the lone pairs of electrons in the Lewis structures.

(i) Lewis structure: 

Structural formula: 

(ii) Lewis structure: 

Structural formula: 

(iii) Lewis structure:

Structural formula:

Think Critically

Scenario

A pharmaceutical company is developing a new medicine.

The research team discovers that one carbon atom has accidentally been drawn with five covalent bonds.

As the chemist responsible for quality control,

• Identify the error. ……

• Explain why the structure is chemically impossible.

……

• Draw the corrected Lewis structure.

……

Try

1. Which pair of electrons forms a covalent bond?

A. Lone pair B. Shared electron pair

C. Inner-shell electrons D. Core electrons

2. Which molecule contains a triple covalent bond?

A. H_2O B. NH_3

C. C_2H_2 D. CH_4

3. Write the Lewis structure and structural formula for each of the following molecules.

(i) HCN

……

(ii) C_3H_8

……

(iii) C_2H_4

……

(iv) C_2H_2

……

Chemistry Shapes Materials

Diamond vs Graphite:

Both consist entirely of carbon atoms.

Different covalent bonding arrangements give them completely different properties.

• Diamond ⟶ hardest natural material .

• Graphite ⟶ soft and conducts electricity.

Be Global Citizen

Modern society depends on synthetic materials made from covalent compounds. These materials improve healthcare, transportation, and communication. However, many plastics made from covalent polymers persist in the environment for centuries.

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Challenge Your Thinking

Scientists can now design entirely new molecules that have never existed in nature.
If you could design a new covalent molecule, what problem would it solve?
Examples:

- biodegradable plastic
- better medicine
- carbon dioxide capture
- clean energy storage

Justify your design scientifically.

.....

Exercise

Write the Lewis structure and structural formula for each of the following molecules:

(i) CCl_4

(ii) CH_4

(iii) HCN

(iv) C_2H_2

(v) C_2H_4

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Lesson 4-2 — Characteristics and Structures of Organic Compounds

Engaging Introduction

Imagine walking into a supermarket where you see hundreds of products that look completely different: plastic water bottles, medicines, perfumes, cooking oil, chocolate, synthetic fabrics, gasoline, and even vitamins.

At first glance, these materials seem to have nothing in common. Yet scientists know that they are all built from the same remarkable element—carbon.

In this lesson, you will investigate how carbon›s unique bonding ability creates the diversity of molecules that support life, modern technology, medicine, agriculture, and industry.

Guiding Question How can changing the arrangement of carbon atoms create substances with completely different properties and uses?

Exploration

Which of these substances do you think have the most similar chemical structures? Explain your reasoning.

- Glucose (sugar)
- Plastic bottle
- Gasoline
- Aspirin
- Candle wax

Point!

1. Organic Compounds

(a) Organic compounds: Compounds with a skeleton of **carbon** atoms.

(b) Characteristics of organic compounds

(i) The number of constituent element types is **small**, but the number of compound types is **large**.

(ii) Many are combustible, and when completely burned, they mainly produce carbon dioxide and water.

(iii) They consist of **molecules** and have **low** melting and boiling points than ionic compounds

(iv) Many are **poorly soluble** in water, but **soluble** in organic solvents such as alcohols.

Liquid organic compounds that act as solvents.

Structure of Science

Key Fact :

- Organic compounds are built around a carbon skeleton.
- Most organic compounds contain carbon and hydrogen, and many also contain oxygen or nitrogen.
- Functional groups determine the chemical properties of organic compounds.

Key Concepts:

- Organic Compounds
- Hydrocarbons
- Functional Groups
- Molecular Structure

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2. Classification of Organic Compounds

(a) Hydrocarbons: Organic compounds consisting only of carbon and hydrogen.

(i) Open-chain hydrocarbons (Aliphatic hydrocarbons): Hydrocarbons in which carbon atoms are bonded in a chain.

- **Alkane**: An open-chain hydrocarbon in which carbon atoms are bonded only by single bonds. The general formula is C_nH_{2n+2}.
- **Alkene**: An open-chain hydrocarbon having one double bond. The general formula is C_nH_{2n}.
- **Alkyne**: An open-chain hydrocarbon having one triple bond. The general formula is C_nH_{2n-2}.

(ii) Cyclic hydrocarbons: Hydrocarbons in which carbon atoms are bonded in a ring.

- **Cycloalkane**: A cyclic hydrocarbon in which carbon atoms are bonded only by single bonds. The general formula is C_nH_{2n}.
- **Cycloalkene**: A cyclic hydrocarbon having one double bond. The general formula is C_nH_{2n-2}.

(b) **Functional group**: A group of atoms that determines the characteristics of a compound.

Table 4-2-1 ⟨Classification of organic compounds by functional groups⟩

Name of functional group	Structure	Name of compound	Name of functional group	Structure	Name of compound
Hydroxyl group	$-OH$	Alcohol	Carboxyl group	$-\overset{\overset{O}{\|\|}}{C}-OH$	Carboxylic acid
Ether linkage	$-O-$	Ether	Ester linkage	$-\overset{\overset{O}{\|\|}}{C}-O-$	Ester
Carbonyl group (Ketone group)	$-\overset{\overset{O}{\|\|}}{C}-$	Ketone	Nitro group	$-NO_2$	Nitro compound
Formyl group (Aldehyde group)	$-\overset{\overset{O}{\|\|}}{C}-H$	Aldehyde	Amino group	$-NH_2$	Amine
			Sulfo group	$-SO_3H$	Sulfonic acid

(c) **Hydrocarbon group:** A part consisting only of carbon and hydrogen other than the functional group. Represented by the symbol R −.

Example: Alcohols are represented as R − OH.

(d) **Condensed structural formula:** A semi-structural formula in which the functional group is shown explicitly while the remaining atoms are written in a condensed (grouped) form.

Example: Ethanol is written as C_2H_5OH rather than the molecular formula C_2H_6O.

The molecular formula is C_2H_6O.

Think Critically

Claim

Organic compounds usually have lower melting and boiling points than many inorganic compounds.

Evidence

Most organic compounds consist of molecules held together by relatively weak intermolecular forces.

Reasoning

Use evidence from the lesson to explain why weaker intermolecular forces lead to lower melting and boiling points.

……

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3. Isomers

Isomers: Compounds with the same molecular formula but different structures.

(i) **Structural isomers**: Isomers with different bonding orders of atoms.

(ii) **Stereoisomers**: Isomers with the same bonding order of atoms but different three-dimensional structures. (3D)

- **Cis-trans isomers**: Stereoisomers that arise because they have a double bond between carbons.
- **Enantiomers**: Stereoisomers that arise because they contain a carbon atom bonded to four different atoms or groups (a chiral carbon atom).

Life Application

Cosmetics

Perfumes, soaps, shampoos and skin-care products depend on organic molecules containing alcohols, esters and aromatic compounds.

Agriculture

Fertilizers, pesticides and herbicides are carefully designed organic compounds that increase crop production.

Warm Up

Answer the following questions.

(a) Among the following descriptions about organic compounds, choose all correct ones.

(i) Organic compounds consist of molecules, and many are soluble in water but poorly soluble in organic solvents.

(ii) For some, even if the molecular formula is the same, there are substances with different ways of bonding atoms and structures.

(iii) Because they are composed of many types of elements, there are many types of organic compounds.

(iv) They have low melting and boiling points.

(v) Carbon dioxide and sodium hydrogen carbonate are organic compounds.

(b) Name the underlined functional groups of the following organic compounds.

(i) H<u>CHO</u> (ii) H<u>COOH</u>

(c) Fill in the blanks with the appropriate words in the following text.

Isomers include (A) isomers, in which the bonding order of atoms is different, and stereoisomers, in which the three-dimensional arrangement of atoms or groups of atoms in a molecule is different. Stereoisomers further include (B) isomers, which are based on double bonds between carbon atoms, and (C), which arise because of the presence of a chiral carbon atom.

Be Global Citizen

Sustainable Organic Chemistry

Organic chemistry is essential for developing:

- Biodegradable plastics
- Renewable biofuels
- Green solvents
- Sustainable fertilizers
- Eco-friendly pharmaceuticals impacts.

Explanation

(a) (i) Many organic compounds are poorly soluble in water and soluble in organic solvents.

(ii) Compounds with the same molecular formula but different structures are called

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isomers.

(iii) There are many types of organic compounds, but the types of constituent elements are few.

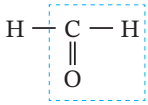
(iv) Because organic compounds consist of molecules, their melting and boiling points are lower than those of inorganic compounds.

This is because the intermolecular forces between organic molecules are weak.

(v) Carbon dioxide CO_2 and sodium hydrogen carbonate $NaHCO_3$ contain carbon atoms but are treated as inorganic substances. Therefore, (ii), (iv) .

(b) (i) The functional group consisting of C, H, O is the formyl group (aldehyde group).

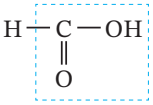
It has a structure like the one on the right.



Formyl group (Aldehyde group)

(ii) The functional group consisting of C, O, O, H is the carboxyl group.

It has a structure like the one on the right.



Carboxyl group

(c) A: Structural B: Cis-trans C: Enantiomer

Think as an Engineer

Scenario

Engineers often need materials that are strong, flexible, lightweight, or biodegradable. Understanding molecular structure and functional groups allows engineers to design plastics, synthetic fibers, adhesives, and medical materials with specific properties.

Which property would be most important when designing a biodegradable food package? Explain your answer.

……

Try

1. Read the following text and answer the questions below.

The types of elements constituting organic compounds are (A), but the types of compounds are extremely (B), and they have (C) structures or cyclic structures.

Also, a group of atoms that determines the characteristics of an organic compound is called a (D). There are also isomers, which are divided into structural isomers and (E). (E) includes (F), which arises because of a double bond, and (G), which arises because of a chiral carbon atom.

(a) Fill in the appropriate words for A to G.

(b) Name the following hydrocarbons (i) to (iii).

(i) A hydrocarbon represented by the general formula C_nH_{2n} and having one double bond between carbon atoms.

(ii) A hydrocarbon represented by the general formula C_nH_{2n}, having no double bonds, and having a cyclic structure.

(iii) A hydrocarbon represented by the general formula C_nH_{2n-2} and having one triple bond between carbon atoms.

(c) Choose all descriptions that correctly describe properties of organic compounds, and write the corresponding letters.

A. Many are poorly soluble in water but soluble in organic solvents.

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B. Many consist of covalent bonds and are electrolytes.

C. Many consist of molecules and have relatively high melting and boiling points.

D. Many are combustible compounds, and often produce water and carbon dioxide upon combustion.

2. Answer the following questions about the compounds below.

(a) $CH_3\underline{CHO}$ **(b)** $CH_3\underline{COCH_3}$ **(c)** $C_2H_5\underline{COOH}$

(d) $C_2H_5\underline{OH}$ **(e)** $C_6H_5\underline{NO_2}$ **(f)** $CH_3\underline{NH_2}$

(i) For the underlined functional groups in each compound, write their respective names.

(ii) What type of organic compound is each, based on its functional group? Write the name of the class. However, *d* is not a phenol.

3. Which of the following descriptions about a pair of enantiomers is incorrect?

(a) Properties such as melting and boiling points are the same.

(b) Their molecular formulas are the same.

(c) Their three-dimensional structures are different.

(d) They have a double bond between carbons within the molecule.

Challenge Your Thinking

Two compounds have the molecular formula C_3H_6O.

One smells pleasant and is used in perfumes.

The other is an important industrial solvent.

Challenge

Without changing the molecular formula, explain how changing only the arrangement of atoms could produce completely different substances.

.....

Exercise

Choose the correct Answer

1. Chemist wants to produce a compound that mixes well with water:

Which functional group would most likely help?

A. Hydrocarbon chain B. Hydroxyl group (–OH)

C. Carbon chain only D. Carbon-carbon triple bond

2. Which property is mainly determined by a functional group?

A. Number of neutrons B. Chemical reactivity

C. Number of protons D. Atomic mass

3. Fill in the blanks with the appropriate words or formulas. Note: Use *n* to represent the number of carbon atoms when writing general formulas.

Organic compounds are compounds with a skeleton of (i) atoms. The types of constituent elements are (ii), and the types of compounds are (iii).

Generally, they consist of (iv) , and their melting and boiling points are (v). Many organic compounds are (vi) in water, but (vii) in organic solvents.

Open-chain hydrocarbons containing one double bond between carbon atoms

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are called (viii) , and their general formula is represented by (ix) ($n \geq 2$). Open-chain hydrocarbons represented by the general formula C_nH_{2n-2} ($n \geq 2$) and having one (x) bond between carbon atoms are called (xi).

4. Answer the following questions about the functional groups below.

(a) Hydroxyl group

(b) Formyl group (Aldehyde group)

(c) Carboxyl group

(d) Ether linkage

(e) Ester linkage

(f) Nitro group

(g) Sulfo group

(h) Amino group

(i) Write the functional groups (a) to (h) as in the example.

(**Example**: Carbonyl group $-\overset{\overset{O}{\|}}{C}-$)

(ii) What are the compounds having the functional groups (a) to (h) called?

5. For the following sentences **(a)** to **(c)**, write *A* if it applies when the two compounds are cis-trans isomers, *B* if it applies when they are enantiomers, *C* if it applies in both cases, and *D* if it applies in neither case.

(a) The molecular formulas are different.

(b) The three-dimensional structures of the molecules are different.

(c) There is a double bond between carbons.

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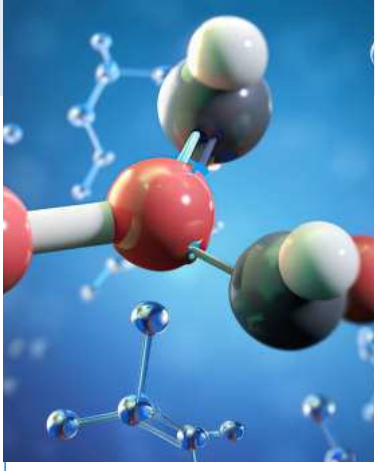
Lesson 4-3 — Determination of Structural Formulas of Organic Compounds



Engaging Introduction

A forensic laboratory discovers an unknown organic compound. Although scientists know it contains carbon, hydrogen, and oxygen, they do not know its identity. By burning a small sample and carefully measuring the products formed, they can gradually reveal the compound›s molecular structure.

In this lesson, you›ll discover how chemists identify unknown compounds using scientific evidence and logical reasoning.

Guiding Question How do particle motion and intermolecular forces determine whether a liquid evaporates, condenses, or boils?

Point!

1. Determination of Structural Formulas

(a) Elemental analysis: A procedure used to determine the proportion of each element present in a compound.

(b) Procedure for determining the structural formula

The structural formula of an organic compound is determined by the following procedure.

Extract a pure sample → Investigate constituent elements → Perform **elemental analysis** → Determine **empirical formula** → Determine **molecular formula** → Determine **structural formula**

(c) Empirical formula: A chemical formula that shows the number of atoms constituting a substance in the simplest integer ratio.

〈How to find the empirical formula〉

The ratio of atom numbers equals the ratio of each element's mass divided by its relative atomic mass. Therefore, for a compound with empirical formula $C_xH_yO_z$,

$$x : y : z = \frac{\text{Mass of C}}{\text{Relative atomic mass of C}} : \frac{\text{Mass of H}}{\text{Relative atomic mass of H}} : \frac{\text{Mass of O}}{\text{Relative atomic mass of O}}$$

Data Detective

A compound contains carbon, hydrogen, and oxygen.
Its elemental analysis gives the following masses:
• Carbon = 24 g
• Hydrogen = 4 g
• Oxygen = 32 g
Without solving completely, predict:
• Which element has the greatest number of atoms?
……
• What information do you need next to determine the molecular formula?
……

Structure of Science

Key fact :

• Elemental analysis determines the elements present in a compound.

• The empirical formula shows the simplest ratio of atoms.

• The molecular formula shows the actual number of atoms.

Key concepts:

Empirical formula-Molecular formula-Structural formula

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(d) Molecular formula: A formula representing the types of constituent elements and the number of atoms of each element constituting a molecule.

〈Empirical formula and molecular formula〉

The molecular formula is the empirical formula multiplied by n (n: integer). The relational expression is: Molecular formula = Empirical formula × n. The value of n is obtained from the relative molecular mass of the compound.

$$n = \frac{\text{Relative molecular mass of Substance}}{\text{Formula weight of empirical formula}}$$

(e) Determination of structural formula: Identify the correct structure by distinguishing among possible isomers on the basis of their functional groups and physical properties, such as melting and boiling points.

Think Critically

Claim

The molecular formula of an organic compound cannot be determined using elemental percentages alone.

Evidence

What evidence supports this claim?

……

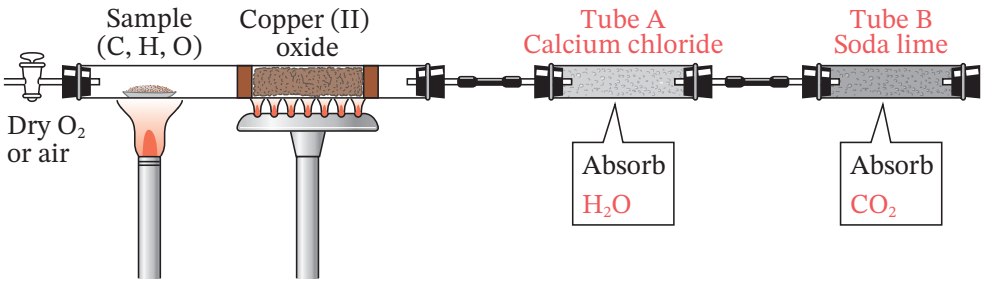
Reasoning

Explain why the relative molecular mass is also required.

……

2. Mass Measurement of Carbon, Hydrogen, and Oxygen

〈Procedure for elemental analysis of a compound consisting of carbon, hydrogen, and oxygen〉



❶ Heat and burn the Weighed sample.

- Add copper(II) oxide. Reason: To ensure **the sample is completely burned** .
- Carbon C becomes **CO_2**, and hydrogen H becomes **H_2O**.

❷ Absorb the generated substances.

- First, absorb **H_2O** in the **calcium chloride** tube.
- Next, absorb **CO_2** in the **soda lime** tube.

Note: The order of the tubes cannot be reversed.

Reason: **Soda lime absorbs both water and carbon dioxide, making it impossible to determine the masses of carbon and hydrogen separately** .

❸ Calculate the masses of carbon and hydrogen from the amount of increase in mass of each tube. (A and B)

❹ Find the mass of oxygen O.

Mass of Oxygen = Mass of Sample − (Mass of Carbon + Mass of Hydrogen)

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Life Application

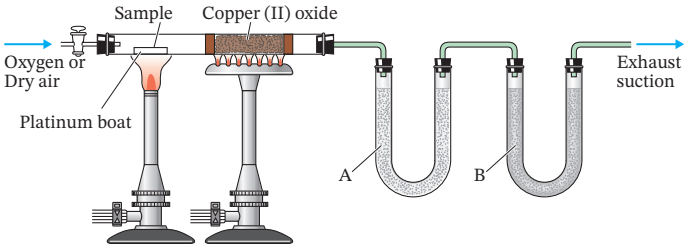
Food Quality Testing

Food scientists determine the carbon, hydrogen, oxygen, and nitrogen contents of foods to measure nutritional value and verify product quality.

Warm Up

Answer the following questions.

When 30.8 mg of organic compound X, consisting of carbon, hydrogen, and oxygen, was completely burned using the apparatus in the figure, the mass increase of tube A was 25.2 mg, and the mass increase of tube B was 61.6 mg. Also, when the relative molecular mass of this compound was measured, it was 88. Answer the following questions. (H = 1.0, C = 12, O = 16)



(a) Regarding the apparatus in the figure, what role does copper(II) oxide play? Answer briefly.

(b) What substances should be packed in tube A and tube B, respectively?

(c) Find the mass of C, the mass of H, and the mass of O contained in organic compound X, with their respective units.

(d) Write the molecular formula of organic compound X.

(e) Write two possible structural formulas of carboxylic acids for organic compound X.

Explanation

(a) To completely burn the sample.

(b) A: Unhydrous Calcium chloride B: Soda lime

(c) Mass of C: CO_2 is absorbed in tube B. Since the mass of tube B increased by 61.6 mg:

$$61.6\ \text{mg} \times \frac{12}{44} = 16.8\ \text{mg}$$

$$\text{Mass of C} = \text{Mass of } CO_2 \times \frac{\text{Relative atomic mass of C}}{\text{Relative molecular massof } CO_2}$$

Mass of H: H_2O is absorbed in tube A. From the mass increase of tube A being 25.2 mg,

$$25.2\ \text{mg} \times \frac{2.0}{18} = 2.80\ \text{mg}$$

$$\text{Mass of H} = \text{Mass of } H_2O \times \frac{\text{Relative atomic mass of H}}{\text{Relative molecular mass of } H_2O}$$

Mass of O: Using Mass of oxygen = Mass of sample − (Mass of carbon + Mass of hydrogen),

30.8 − (16.8 + 2.80) = 11.2 mg.

From the above, Mass of C: 16.8 mg Mass of H: 2.80 mg Mass of O: 11.2 mg.

(d) First, find the empirical formula of the compound. Assuming the empirical formula is $C_xH_yO_z$, from (c),

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$x : y : z = \frac{16.8}{12} : \frac{2.8}{1.0} : \frac{11.2}{16}$

$= 1.4 : 2.8 : 0.7$

$= 2 : 4 : 1$

Therefore, the empirical formula of this compound is C_2H_4O.

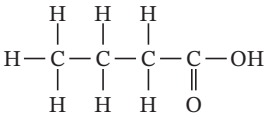
Next, using Molecular formula = Empirical formula × n: since the formula weight of C_2H_4O is 44 and the relative molecular mass is 88,

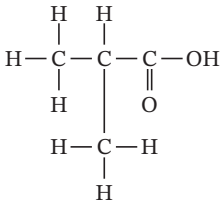
$n = \frac{88}{44} = 2$

$n = \frac{\text{Relative molecular mass}}{\text{Formula weight of empirical formula}}$

Therefore, the desired molecular formula is twice C_2H_4O, which is $C_4H_8O_2$.

(e) Since carboxylic acids possess a carboxyl group —C(=O)—OH, Two possible structural formulas for $C_4H_8O_2$ are:





For the three carbon atoms excluding the carboxyl group, it is conceivable that they are unbranched.

Think as an Engineer

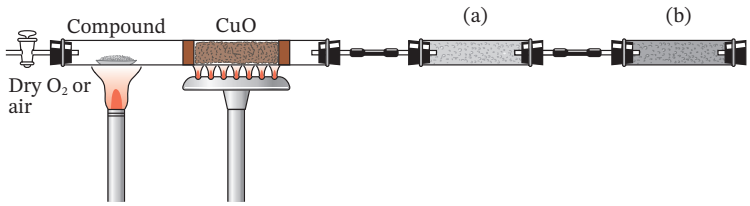
Chemical engineers use combustion analysis to verify the identity and purity of substances used in medicines, foods, and industrial chemicals.

How does accurate chemical analysis improve product quality and public safety?

……

Try

1. Using the apparatus shown on the right, determine the structural formula of an unknown organic compound. When 1.02 g of an organic compound composed of carbon, hydrogen, and oxygen was completely combusted, 2.2 g of carbon dioxide and 0.90 g of water were obtained. Answer the following questions. (H = 1.0, C = 12, O = 16)



(i) What is the role of CuO? Select the best answer from A to D.

A To prevent incomplete combustion of the sample.

B To increase heat retention in the glass tube.

C To make the reaction proceed faster.

D To keep the inside of the glass tube dry.

(ii) To determine the mass of carbon dioxide produced, which tube — (a) or (b) — should you compare before and after the reaction?

(iii) What should be put in (a) and (b), respectively? Choose one each from A to F below

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and select the appropriate letters.

(A) Silicon dioxide
BCalcium hydroxide
(C) Limestone
(D) Sodium hydrogen carbonate
(E) Calcium chloride
(F) Soda lime

(iv) Can this experiment be performed if the order of (a) and (b) is reversed? Explain your reasoning based on the properties of the substances in the tubes.

(v) Find the empirical formula of this organic compound.

(vi) Assuming the relative molecular mass of this organic compound is 102, find its molecular formula.

(vii) Among the structural isomers of this organic compound, write one that has a carboxyl group.

.....

2. When 30.0 g of compound A consisting only of carbon, hydrogen, and oxygen was completely burned, 66.0 g of carbon dioxide and 36.0 g of water were produced. Answer the following questions. (H = 1.0, C = 12, O = 16)

(a) What is the mass of carbon contained in 30.0 g of compound A? Report your answer to two significant figures.

(b) What is the mass of hydrogen contained in 30.0 g of compound A? Report your answer to two significant figures.

(c) What is the mass of oxygen contained in 30.0 g of compound A? Report your answer to two significant figures.

(d) Write the empirical formula of compound A.

(e) Find the molecular formula of compound A. Assume the relative molecular mass of compound A is 180..

.....

Exercise

Choose the Correct Answer

1.During combustion analysis, why is copper(II) oxide added?

A. To absorb carbon dioxide
B. To absorb water vapor
C. To ensure complete combustion
D. To cool the gases

.....

2.Which instrument collects water produced during combustion?

A. Soda lime
B. Calcium chloride
C. Copper oxide
D. Platinum catalyst

.....

Answer the following questions

3. Consider an organic compound X consisting only of carbon, hydrogen, and oxygen. An elemental analysis of organic compound X was performed using the apparatus shown in the figure below. Answer the questions below. (H = 1.0, C = 12, O = 16)

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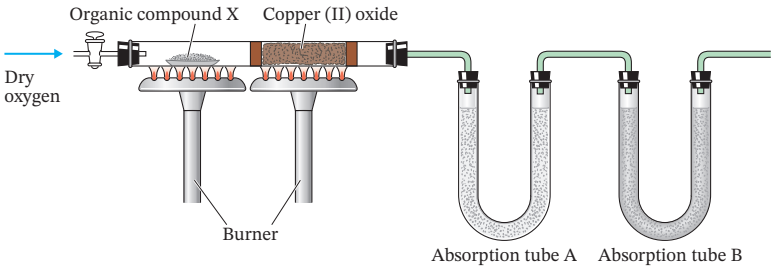

(i) What is the role of copper (II) oxide? Select the best answer from the following.

a A reducing agent to completely reduce X

b An oxidising agent to completely oxidise X

(ii) Which substance should be placed in absorption tube A? Select the appropriate letter from the following.

a Soda lime

b Sodium chloride

c Calcium chloride

d Calcium carbonate

(iii) Which substance is absorbed by absorption tube B? Select the appropriate letter from the following.

(a) Carbon dioxide

(b) Ammonia

(c) Water vapour (Water)

(d) Oxygen

(iv) When 72 mg of compound X was completely burned, the mass of absorption tube A increased by 72 mg and the mass of (d)ɔrption tube B increased by 176 mg. Which is the empirical formula of X? Choose one from the following and select the appropriate letter.

(a) C_4H_8O

(b) $C_8H_{16}O_2$

(c) $C_4H_8O_2$

(d) C_6H_2O

(e) $C_{12}H_4O_2$

.....

4. Based on the results of (I) and (II) below, answer the questions below. (H = 1.0, C = 12, O = 16)

(I) When 6.0 mg of organic compound A consisting of carbon, hydrogen, and oxygen was completely burned, 13.2 mg of carbon dioxide and 7.2 mg of water were produced.

(II) When 6.0 mg of organic compound A was heated in a 300 mL container at 27°C and 8.3×10^5 Pa until it became a gas, the relative molecular mass was calculated from the ideal gas law to be 60.

(a) Find the empirical formula of organic compound A.

(b) Find the molecular formula of organic compound A.

(c) Write one possible structural formula of an alcohol for organic compound A.

.....

Challenge Your Thinking

Suppose another unknown compound produced:

• 44 mg CO_2 • 18 mg H_2O

Without completing every calculation: Predict whether this compound contains more carbon or more oxygen than the previous sample.

.....

Justify your prediction.

.....

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Lesson 4-4 — Saturated Hydrocarbons

Engaging Introduction

Imagine two camping trips.

On one trip, a camper lights a portable gas stove, and the fuel burns with a clean blue flame, heating water within minutes.

On another trip, someone accidentally spills gasoline onto the ground. The fuel evaporates quickly, creating a dangerous fire hazard.

Although both fuels are made mainly of alkanes, they behave differently depending on their molecular structures.

Guiding Question How can the structure of an alkane explain its physical properties, chemical reactions, and practical uses in everyday life?

Exploration

Observe the following two compounds.

Compound A:

A hydrocarbon with five carbon atoms arranged in a straight chain, where each carbon atom is connected in a continuous sequence.

Compound B:

A hydrocarbon with the same molecular formula (C_5H_{12}), but with the carbon atoms arranged in a branched chain, forming a different structural pattern.

Based on your observations,Think about the following questions:

1.What similarities do you observe between Compounds A and B?.....

2.How does the arrangement of the carbon atoms differ in each compound?.....

Point!

Alkane

(a) Saturated hydrocarbons: Hydrocarbons in which carbon atoms are bonded only by single bonds.

Table 4-4-1 〈Straight-chain alkanes〉

Number of carbons	Name	Molecular formula
1	Methane	CH_4
2	Ethane	C_2H_6
3	Propane	C_3H_8
4	Butane	C_4H_{10}
5	Pentane	C_5H_{12}
6	Hexane	C_6H_{14}

(b) Alkane: Open-chain saturated hydrocarbons.

The general formula is C_nH_{2n+2}. (Table 4-4-1 on the right)

(c) Alkyl group: A hydrocarbon group formed by removing one hydrogen atom from an alkane molecule. (Table below)

Structure of Science

Key fact :

- Alkanes are saturated hydrocarbons.
- They contain only single covalent bonds.
- They undergo substitution reactions with halogens.

Key Concepts:

Alkane- Saturated hydrocarbons- Alkyl group- Cycloalkane- a substitution reaction- substituent

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Table 4-4-2 〈Examples of alkyl groups〉

Name	Structure
Methyl group	CH_3-
Ethyl group	CH_3CH_2-
Propyl group	$CH_3CH_2CH_2-$
Isopropyl group	$CH_3CH(-)CH_3$

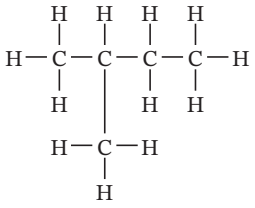
- In branched alkanes, the longest continuous chain of carbon atoms is called the main chain, and the branches are called side chains.

(d) Nomenclature of alkanes

Table 4-4-2

- The name of a branched alkane is constructed as: Position number of the side chain + Name of the side chain + Name of the main chain .

Example: Regarding the alkane on the right,



- The position of the side chain is 2 .
- The side chain is a methyl group.
- The main chain is butane .

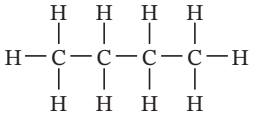
→ The name is 2-methylbutane.

- Number the chain so that the position number of the side chain is as small as possible.
- When there are multiple identical side chains, use the prefixes di- (2), tri- (3), or tetra- (4) before the side-chain name.

(e) Structure of alkanes

- Alkanes with 4 or more carbon atoms have structural isomers.

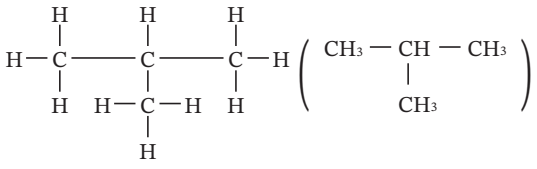
Example: There are two structural isomers with 4 carbon atoms.



Butane

Structural formulas are sometimes written in a simplified way as follows.

$CH_3-CH_2-CH_2-CH_3$

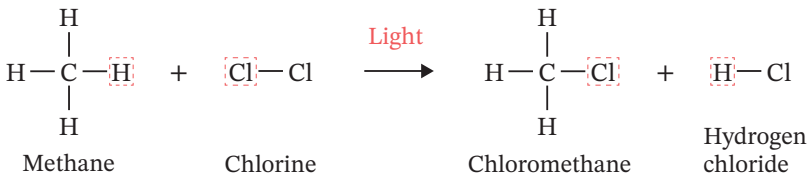


2-Methylpropane

(f) Reactions of alkanes

- When completely burned, they produce carbon dioxide and water.
- When a mixture of an alkane and a halogen is exposed to light, the hydrogen atoms in the alkane molecule are replaced by halogen atoms.

Example: Reaction of methane and chlorine



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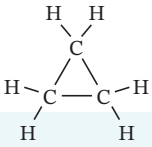
Note: A reaction in which an atom or group of atoms in a molecule is replaced by another atom or group of atoms in this way is called a **substitution reaction**, and the atom or group of atoms that takes the place of the original atom or group is called a **substituent**. (The replaced atom or group is referred to as the leaving group.)

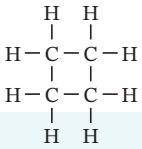
(g) Cycloalkane: Cyclic saturated hydrocarbons.
The general formula is C_nH_{2n} $(n \geq 3)$.

⟨Examples of cycloalkanes⟩

Cyclopropane



Cyclobutane



Life Application

Different fuels contain different alkanes.

- Natural gas (Methane) Methane is used in homes as Fuel because it burns cleanly.
- Propane fuels portable stoves and camping equipment.
- Gasoline powers cars.
- Diesel contains longer-chain hydrocarbons for heavy vehicles.

Warm Up

Answer the following questions.

(a) Name the substance represented by the following structural formula.

$$CH_3 - CH_2 - CH_2 - CH_3$$

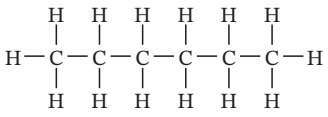
(b) Write all structural formulas and names for the structural isomers of the alkane with the molecular formula C_6H_{14}.

Explanation

(a) Because it is a straight-chain alkane with 4 carbon atoms, it is butane.

(b) There are 5 isomers of the alkane with 6 carbon atoms.

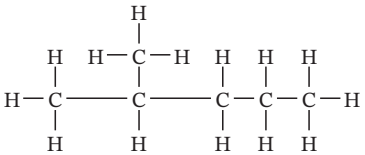
Structural formula:



Straight chain

Name: Hexane

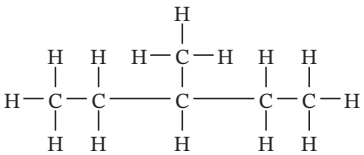
Structural formula:



The main chain has 5 carbon atoms, and the side chain is connected to the 2nd carbon atom.

Name: 2-Methylpentane

Structural formula:



The main chain has 5 carbon atoms, and the side chain is connected to the 3rd carbon atom.

Name: 3-Methylpentane

Structural formula:

Be Global Citizen

Burning fossil fuels releases carbon dioxide that contributes to climate change.
Scientists and engineers are developing cleaner fuels such as biofuels, green hydrogen, and synthetic hydrocarbons to reduce environmental impacts.

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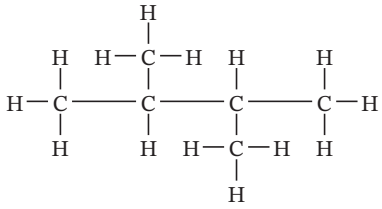
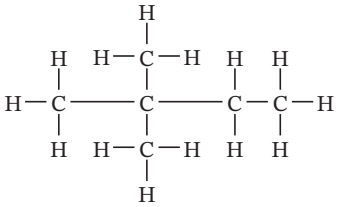


The main chain has 4 carbon atoms, and the side chains are connected to different carbon atoms.

Name: 2,3-Dimethylbutane

Structural formula:



The main chain has 4 carbon atoms, and the side chains are connected to the same carbon atom.

Name: 2,2-Dimethylbutane

Prediction

Methane reacts very slowly with chlorine in darkness.
Predict what will happen if the mixture is exposed to ultraviolet light.
Explain your reasoning before reading the reaction

Try

1. Answer the following questions.

(a) Fill in the blanks with the appropriate words in the following text.

In straight-chain hydrocarbons, they are named according to the number of carbon atoms, such as CH_4 is methane, C_2H_6 is (i) , C_3H_8 is propane, and C_4H_{10} is (ii) , which is the basis for the nomenclature of organic compounds.

(b) For each blank in the following sentences, select one from A to D.

(i) When an alkane is mixed with chlorine or bromine and ( ), a substitution reaction occurs.

A Warmed slowly　　B Irradiated with light

C Heated at high temperature　　D Left in the shade

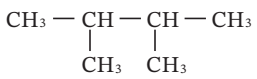
(ii) For the alkane represented by C_5H_{12}, there are ( ) types of structural isomers.

A 2　　B 3　　C 4　　D 5

2. Answer the following questions about organic compounds.

(a) Name the substance represented by the following structural formula.

(i) $CH_3 - CH_2 - CH_2 - CH_2 - CH_3$

(ii) 

(b) Write the structural formulas for the following substances. If there is more than one possibility, draw all of them.

(i) Cyclopentane　　(ii) Alkane represented by C_4H_{10}

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Exercise

Choose the correct answer:

1. A hydrocarbon has the molecular formula C_5H_{12}.

What explains why it has three different structures?

A. Different molecular masses

B. Different functional groups

C. Different arrangements of carbon atoms

D. Different numbers of hydrogen atoms

2. A chemist exposes methane and chlorine to sunlight.

Which type of reaction occurs?

A. Addition B. Combustion

C. Substitution D. Neutralization

3. Fill in the blanks with the appropriate words, chemical formulas, or numbers. For the general formula, use n to represent the number of carbon atoms.

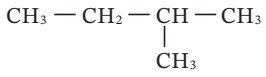
Acyclic hydrocarbons with no unsaturated bonds (double or triple bonds) are collectively called (i), and are represented by the general formula (ii). When straight-chain (i)s are listed in increasing order of their carbon atoms, they are (iii), ethane, (iv), butane, (v), and so on. Structural isomers exist for (i)s with (vi) or more carbon atoms; for example, butane has 2 isomers and (v) has (vii). These compounds are highly flammable, and their complete combustion produces (viii) and (ix) (in either order).

4. Answer the following questions about organic compounds.

(a) Name the substance represented by the following structural formula.

(i) $CH_3 — CH_2 — CH_2 — CH_2 — CH_2 — CH_3$

(ii)



(b) Write the structural formulas for the following substances. If there is more than one possibility, write all of them.

(i) Cyclopropane (ii) Alkane represented by C_5H_{12}

Challenge Your Thinking

Cycloalkanes and straight-chain alkanes can have the same molecular formula.

For example,

Cyclobutane → C_4H_8 Butene → C_4H_8

Why does one belong to saturated hydrocarbons while the other is unsaturated?

.....

Explain using bonding and molecular structure.

.....

Chemistry Across Disciplines

Engineers study alkanes when designing efficient fuels. Environmental scientists monitor hydrocarbon emissions. Geologists investigate hydrocarbons during petroleum exploration.

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Lesson 4-5 — Unsaturated Hydrocarbons (1) (Alkenes)

Engaging Introduction

Every day, millions of plastic bags, bottles, pipes, and food containers are manufactured from a simple gas called ethylene. At the same time, the very same molecule helps fruits ripen naturally on trees and in storage facilities. How can one small molecule play such different roles?

In this lesson, we will explore how the presence of a carbon–carbon double bond gives alkenes distinctive properties, explains their chemical reactions, and makes them valuable in both biological systems and industrial applications.

Guiding Question How does the presence of a carbon–carbon double bond change the properties, reactions, and applications of organic compounds?

Exploration

Look at the following everyday objects:

- A green banana
- A ripe banana
- A plastic shopping bag
- A plastic bottle

Although they appear completely different, they are connected by the same simple molecule: ethene (ethylene).

Think about

- What changes as a banana ripens?

……

- Why are many everyday plastics made from ethene?

……

- What properties of this molecule make it useful in both living organisms and industry?

……

Point!

1. Alkenes

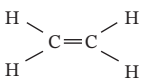
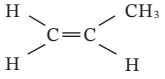
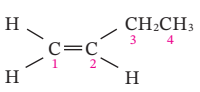
(a) **Unsaturated hydrocarbons:** Hydrocarbons having double bonds between carbon atoms.

(b) **Alkene:** An open-chain unsaturated hydrocarbon having one double bond. The general formula is C_nH_{2n} .

(c) **Nomenclature of alkenes** (Table on the right)

- The name of an alkene is formed by changing the suffix "-ane" of the alkane with the same number of carbons to "-ene".

Table 4-5-1 〈Examples of alkenes〉

Number of carbons	Name	Structural formula
2	Ethene (Ethylene)	
3	Propene (Propylene)	
4	1-Butene	

structure of science

Key fact :

The carbon–carbon double bond is one of the most reactive features in organic chemistry because it contains a region of high electron density that can easily participate in chemical reactions.

Key concepts:

Unsaturated hydrocarbons- Cis-trans isomers- Cycloalkene- Addition reaction- Addition polymerization.

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• For alkenes with four or more carbon atoms, the position of the carbon atom forming the double bond is indicated by the lowest chain number.

(d) Properties of alkenes

• The carbon atoms forming the double bond C=C and the four atoms directly bonded to them are on the **same plane** (coplanar).

(e) Cis-trans isomers (Geometric isomers)

(i) Cis isomer: Isomers in which identical atoms or groups are on **the same side** of the double bond.

(ii) Trans isomer: Isomers in which identical atoms or groups are on **opposite sides** of the double bond.

Example: Cis-trans isomers of 2-butene

(i) Cis isomer (Cis-2-butene) (ii) Trans isomer (Trans-2-butene)

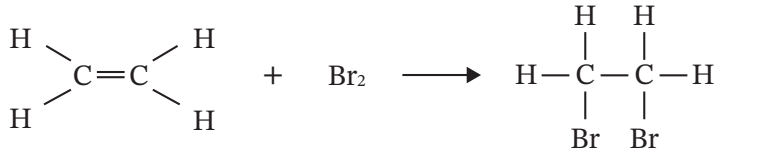
(f) Cycloalkene: A cyclic unsaturated hydrocarbon having one double bond. The general formula is C_nH_{2n-2} ($n \geq 3$).

2. Reactions of Ethylene C_2H_4

(a) Manufacturing process of ethylene: Ethylene is produced by heating a mixture of ethanol and **concentrated sulfuric acid** to **160–170** °C. • Ethanol C_2H_5OH is dehydrated.

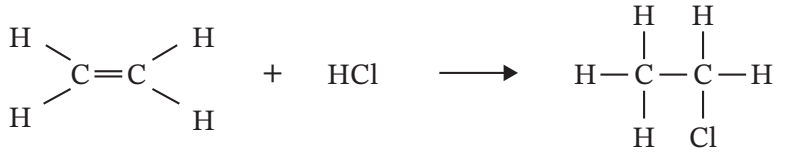
(b) **Addition reaction**: A reaction in which other atoms or groups of atoms bond to an unsaturated bond such as a double bond. By addition reaction, a double bond becomes a single bond.

• Addition reaction of bromine



Ethylene Bromine **1, 2-Dibromoethane**

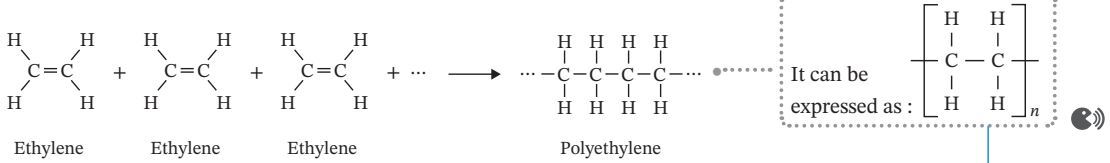
• Addition reaction of hydrogen chloride



Ethylene Hydrogen chloride **Chloroethane**

(c) **Addition polymerization**: A reaction in which many molecules of Alkene undergo successive addition reactions to form a long-chain polymer.

• Production of polyethylene



Ethylene Ethylene Ethylene Polyethylene

It can be expressed as :

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Life Application

Fruits such as bananas, apples, and tomatoes release ethylene gas as they ripen. Commercial fruit storage facilities carefully control ethylene concentration to delay ripening during transport or accelerate ripening before products reach supermarkets.

Warm Up

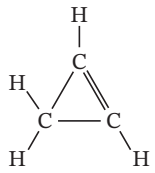
Answer the following questions.

(a) Answer the following questions (i) and (ii) .

(i) Name the substances represented by the following structural formulas.

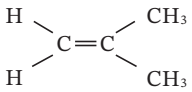
(A) $CH_2=CH-CH_2-CH_2-CH_3$

(B)

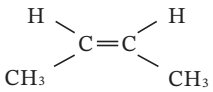


(ii) Among the following, select the structural formula of the substance that has cis-trans isomers (choose from A to C)

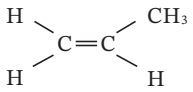
A



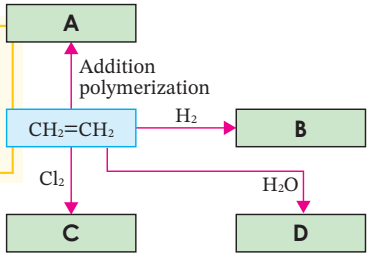
B



C



(b) Answer the following questions about the figure on the right showing the reactions of ethylene.



(i) Write the structural formulas of the substances A to C.

(ii) Name the substances A to D.

Explanation

(a) (i) A: Change the suffix "-ane" of pentane, an alkane with 5 carbon atoms, to "-ene" to get pentene. Furthermore, since the double bond is at the first carbon atom, it is 1-pentene.

The position of the double bond is counted from the direction that gives the smaller number.

B: Since it is a cycloalkene with 3 carbon atoms, it is cyclopropene.

(ii) If the same atoms or groups of atoms are bonded to the carbon atoms forming the double bond C=C, cis-trans isomers do not exist. In A, the same atoms or groups of atoms are bonded to both carbon atoms, and in C, the atoms bonded to one carbon atom are the same, so cis-trans isomers do not exist. Therefore, B.

(b) (i) A: When ethylene is subjected to addition polymerization, it reacts as follows.

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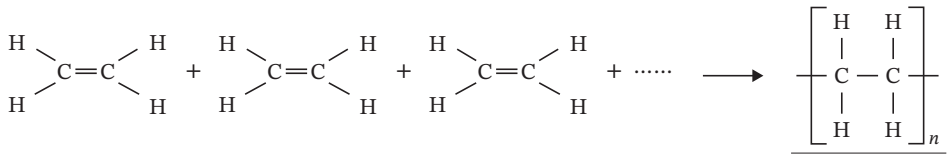
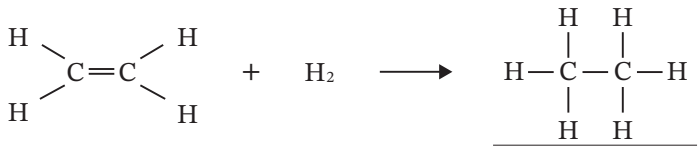
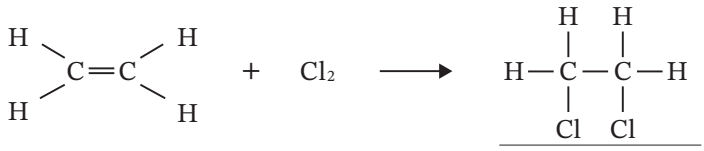


B: When ethylene and hydrogen H_2 react, the following addition reaction occurs.

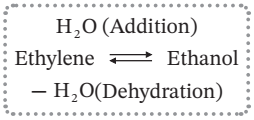


C: When ethylene and chlorine Cl_2 react, the following addition reaction occurs.



(ii) A: Polyethylene B: Ethane C: 1, 2-Dichloroethane

D: When ethanol is dehydrated, ethylene is obtained. Conversely, when water H_2O is added to ethylene, ethanol is produced. Ethanol



Think Critically

Scenario

Scientists discover two hydrocarbons with the same molecular formula C_4H_8.
One reacts rapidly with bromine water.
The other reacts much more slowly.
Without performing any additional tests, what might you infer about their molecular structures?
Explain your reasoning.

.....

Try

1. Answer the following questions about unsaturated hydrocarbons.

(a) What is the name of a reaction in which atoms or groups of atoms add across an unsaturated bond such as a double or triple bond?

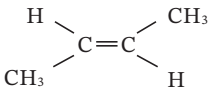
(b) What is the name of the reaction in which many molecules undergo the reaction in **(a)** successively to form a long-chain polymer?

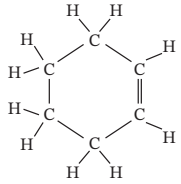
(c) Write the structural formula and name of the substance obtained by subjecting $CH_2 = CH_2$ to the reaction in **(b)**.

2. Answer the following questions about organic compounds.

(a) Name the substances represented by the following structural formulas.

(i) $CH_2 = CH - CH_2 - CH_3$

(ii) 

(iii) 

Be Global Citizen

Every year, millions of tons of polyethylene are produced from ethylene.
Although plastics improve modern life, improper disposal contributes to global pollution.
Scientists worldwide are developing biodegradable plastics and advanced recycling technologies to create a more sustainable future.

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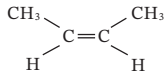
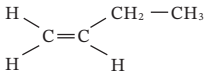
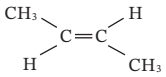
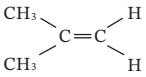
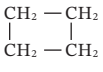
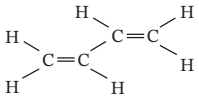
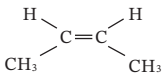
(b) Answer the following questions about the structural formulas (A) to (G).

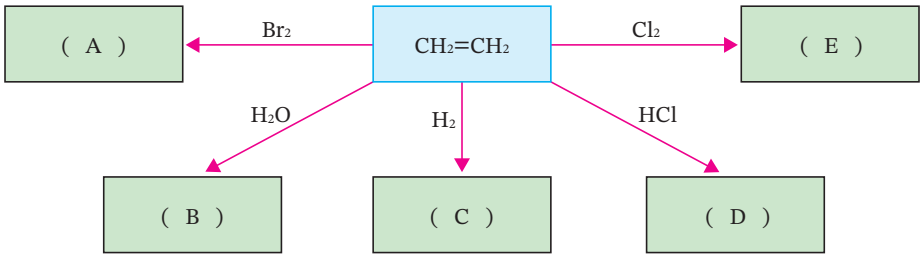
(A)  (B)  (C)  (D) 

(E)  (F)  (G) 

(i) Choose all substances that are structural isomers of (A) from (B) to (G).

(ii) Choose all substances that are cis-trans isomers of (A) from (B) to (G).

3. Answer the following questions about the figure below showing the reactions of $CH_2 = CH_2$.



(a) Name the substances (A) to (E).

(b) Write the structural formulas of the substances (A) to (E).

Exercise

Choose the correct answer:

1- A chemist wants to produce polyethylene.

Which reaction should be used?

A. Combustion
B. Substitution
C. Condensation
D. Addition polymerization

2. Which experimental observation provides evidence that an unknown compound is unsaturated?

A. It dissolves in water.
B. It has a low boiling point.
C. It burns with a blue flame.
D. It decolorizes bromine water.

3. Choose the appropriate words or chemical formulas for the blanks in the following sentences from A to D, one by one, and select the appropriate letters.

(a) Alkenes have the same general formula as ( ) with the same number of carbons.

(A) Alkanes
(B) Alkynes
(C) Cycloalkanes
(D) Carboxylic acids

(b) ( ) has cis-trans isomers.

(A) $CH_2 = CH_2$
(B) $CH_3CH = CH_2$
(C) $CH_2 = CHCH_3$
(D) $CH_3CH = CHCH_3$

Chemistry Across Disciplines

- Engineers design stronger plastics using polymer chemistry.
- Agricultural scientists use ethylene to control fruit ripening.
- Environmental scientists investigate biodegradable polymers.
- Biomedical engineers develop polymer-based artificial joints and prosthetic materials.

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(c) In ( ), all atoms are on the same plane.

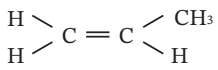
(A) Methane **(B)** Ethane

(C) Ethylene **(D)** Cyclopropane

4. Answer the following questions about organic compounds.

(a) Name the substances represented by the following structural formulas.

(i) $CH_3-CH=\underset{\displaystyle CH_3}{\overset{\displaystyle |}{C}}-CH_3$

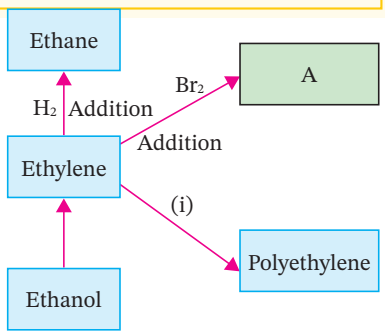
(ii) 

(b) Write the structural formulas for (i) to (iv) to meet the following conditions.

[Conditions]

- (i) to (iv) are all alkenes represented by the molecular formula C_4H_8.
- The name of the substance having the structural formula (i) is 1-butene.
- (i), (ii), and (iii) are structural isomers of each other.
- (iii) and (iv) are cis-trans isomers of each other, and (iii) is the cis isomer.

5. The figure on the right shows the interrelationship of the reactions of organic compounds. Answer the following questions.



(a) Ethylene is produced by the intramolecular dehydration of ethanol. Choose the correct operation for this from the following select the appropriate letter.

(A) Add concentrated hydrochloric acid to ethanol and heat at about 130–140°C.

(B) Add concentrated sulfuric acid to ethanol and heat at about 130–140°C.

(C) Add concentrated hydrochloric acid to ethanol and heat at about 160–170°C.

(D) Add concentrated sulfuric acid to ethanol and heat at about 160–170°C.

(b) Name compound A.

(c) What is reaction (i) called? Select one answer from A to E.

(A) Neutralization **(B)** Integration

(C) Dehydration **(D)** Polymerization

(E) Reduction

Challenge Your Thinking

Polyethylene is made entirely from carbon and hydrogen.

Why doesn't it behave like ethylene?.....

Explain how changing molecular size changes material properties.

.....

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Lesson 4-6 — Unsaturated Hydrocarbons (2) (Alkynes)

Engaging Introduction

Imagine watching a welder repair a bridge using an extremely hot flame that can melt steel within seconds. Surprisingly, the fuel responsible for this intense flame is a simple hydrocarbon called acetylene. The same molecule is also used to manufacture plastics, synthetic fibers, and many important industrial chemicals.

In this lesson, we will explore how the unique carbon–carbon triple bond gives alkynes their distinctive structure, high reactivity, and wide range of industrial applications.

Guiding Question How does replacing a double bond with a triple bond change the properties and chemical behavior of a hydrocarbon?

structure of science

Key fact :

A carbon–carbon triple bond consists of one sigma (σ) bond and two pi (π) bonds, making alkynes more reactive than alkanes and suitable for many addition reactions

Exploration

Acetylene is used in welding because its flame can reach temperatures above 3000°C, making it hot enough to cut and join metals.

At the same time, chemists use acetylene as a starting material for producing plastics, synthetic rubber, pharmaceuticals, and other valuable chemicals.

Think about

• Why can one small molecule release so much energy?

.....

• What feature of its structure makes it more reactive than many other hydrocarbons?

.....

Point!

1. Alkynes

(a) Alkyne: An open-chain unsaturated hydrocarbon having one **triple bond** . The general formula is C_nH_{2n-2} .

(b) Nomenclature of alkynes: The suffix "-ane" of the alkane with the same number of carbon atoms is changed to "-yne".

(c) Structure of alkynes: The carbon atoms forming the triple bond C≡C and the two atoms directly bonded to them are in a **straight line** (linear). Alkynes do not have cis-trans isomers.

NOS: Prediction

Acetylene reacts with bromine much faster than methane.

Predict:

Why would one hydrocarbon react immediately while another shows almost no reaction under the same conditions?

.....

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2. Reactions of Acetylene C_2H_2

The structural formula of acetylene is CH ≡ CH.

(a) Preparation process of acetylene: Acetylene is produced by adding water to _ **calcium carbide** (CaC_2).

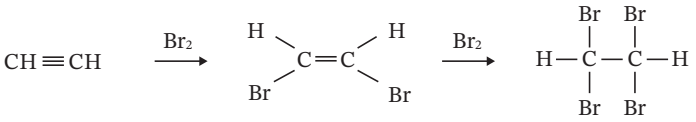
$$CaC_2 + 2H_2O \longrightarrow C_2H_2 + Ca(OH)_2$$

(b) Addition reactions

(i) Addition of hydrogen molecules: Adding 1 molecule of hydrogen produces _ **ethylene** .

Adding 2 molecules produces **ethane** .

(ii) Addition of halogens: 2 molecules of halogen add to 1 molecule of acetylene.



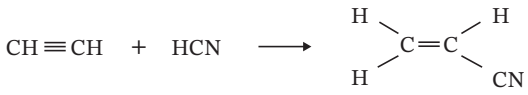
1,2-Dibromoethylene — **1, 1, 2, 2-Tetrabromoethane**

(iii) Addition of other substances

- Addition of hydrogen chloride HCl: Produces **vinyl chloride** $CH_2 = CHCl$.

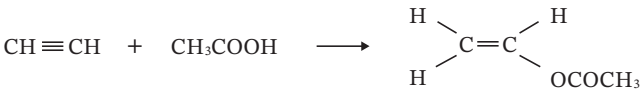
Vinyl chloride (Chloro ethene)

- Addition of hydrogen cyanide HCN: Produces **acrylonitrile** $CH_2 = CHCN$.



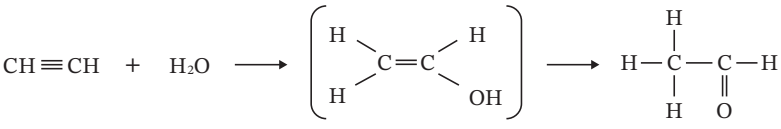
Acrylonitrile

- Addition of acetic acid CH_3COOH: Produces **vinyl acetate** $CH_2 = CHOCOCH_3$.



Vinyl acetate

- Addition of water H_2O: Produces **acetaldehyde** CH_3CHO via unstable vinyl alcohol.



Vinyl alcohol (Unstable) — **Acetaldehyde**

(iv) Trimerization (Polymerization of 3 molecules): 3 molecules of acetylene cyclotrimerize to form **benzene** C_6H_6.

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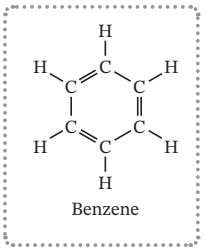

Benzene

Life Application

Acrylonitrile is used to manufacture:

- Carbon fibers for aircraft
- Sports equipment
- Automotive components.
- Protective helmets
- Synthetic textiles

Warm Up

Answer the following questions:

(a) Name the following substances (i) and (ii).

(i) $CH \equiv C - CH_3$ (ii) $CH_3 - C \equiv C - CH_3$

(b) Write the structural formula and name of the substance produced when the following substances (i) to (iv) are added to 1 molecule of acetylene.

(i) 1 molecule of hydrogen

(ii) 2 molecules of hydrogen

(iii) 2 molecules of bromine

(iv) 1 molecule of water

Explanation

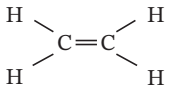
(a) (i) Change the suffix "-ane" of propane, an alkane with 3 carbon atoms, to "-yne". Propyne

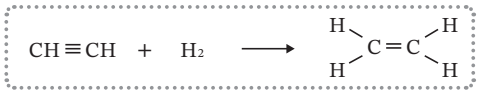
The position of the Triple bond is counted from the direction that gives the smaller number.

(ii) Change the suffix "-ane" of butane, an alkane with 4 carbon atoms, to "-yne" to get butyne. Also, since the triple bond is at the second carbon atom, it is 2-butyne.

(b) (i) Structural formula:

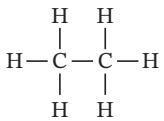
Name : Ethylene(Ethene)

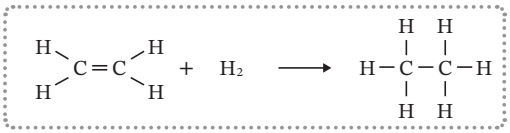




(ii)Structural formula:

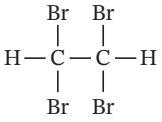
Name : Ethane





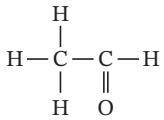
(iii) Structural formula:

Name : 1, 1, 2, 2- Tetrabromoethane



(iv) Structural formula:

Name : Acetaldehyde



When 1 molecule of water is added, it first becomes vinyl alcohol $CH_2 = CHOH$, but because this is unstable, it becomes acetaldehyde.

Be Global Citizen

Vinyl chloride is the starting material for PVC (polyvinyl chloride), one of the world's most widely used plastics.

PVC is used in:

- Drinking water pipes
- Electrical insulation
- Medical tubing
- Window frames.

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Try

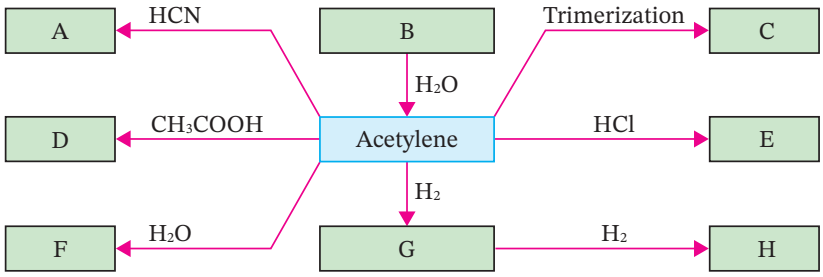
1. Answer the following questions about organic compounds.

(a) Name the substances represented by the following structural formulas.

(i) $CH \equiv CH$ (ii) $CHBr_2 - CHBr_2$

(b) Write the structural formulas of 1-butyne and 2-butyne, which are structural isomers of each other.

2. The figure on the right shows the synthetic pathway of organic compounds related to acetylene.



2- Answer the following questions.

(a) Name the substances corresponding to A to H.

(b) Which statement about substance G is correct? Select one from I to IV.

(i) The bond between carbon atoms can rotate.

(ii) When 1 molecule of chlorine Cl_2 is added, 1, 1-dichloroethane is produced.

(iii) All constituent atoms exist on the same plane.

(iv) Substitution reactions occur easily.

(c) Write the structural formula of the substance produced when 2 molecules of bromine Br_2 are added to 1 molecule of acetylene.

Exercise

Choose the correct answer:

1. Which industrial application depends directly on acetylene's high combustion temperature?

A. Water purification B. Food preservation

C. Metal welding D. Fertilizer production

2. Which product is obtained when three acetylene molecules react together?

A. Ethane B. Cyclohexane

C. Polyethylene D. Benzene

Answer the following question:

3. Answer the following questions about organic compounds.

(a) Name the substances represented by the following structural formulas.

(i) $CH \equiv C - CH_3$ (ii) $CH \equiv C - CH_2 - CH_3$

(b) Write the structural formulas of the following substances.

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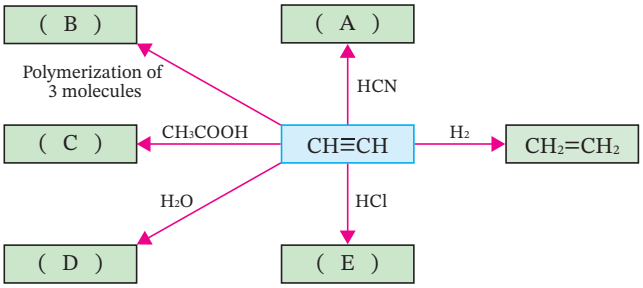
(i) 2-Butyne (ii) 1, 1, 2, 2-Tetrabromoethane

4. Answer the following questions about the figure on the right showing the reactions of CH ≡ CH.



(a) Write the structural formulas and names of (A) to (E).

(b) Choose the laboratory manufacturing process of CH ≡ CH in the figure from I to IV below.

I Add ethanol C_2H_5OH while heating concentrated sulfuric acid to 160–170°C.

II Add ethanol C_2H_5OH while heating concentrated sulfuric acid to about 130°C.

III Add calcium carbide CaC_2 to water.

IV Mix sodium acetate CH_3COONa and sodium hydroxide and heat.

Challenge Your Thinking

Three molecules of acetylene combine to form benzene.

How can several small molecules join together to produce a completely different compound with new properties?

.....

What advantages might this transformation provide in chemical manufacturing?

.....

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Lesson 4-7 — Alcohols and Ethers

Engaging Introduction

Imagine walking into a hospital and noticing the strong smell of hand sanitizer. Later, you see a racing car fueled with bioethanol, and at home someone uses rubbing alcohol to disinfect a wound.

These very different products all belong to the same family of organic compounds—alcohols— and Ethers yet they behave differently because of small differences in their molecular structures.

In this lesson, we will explore how the structure of alcohols and ethers determines their physical properties, chemical reactions, and their many applications in medicine, industry, transportation, and everyday life.

Guiding Question How does changing the structure of an alcohol or ether change its physical properties, chemical behavior, and practical applications?

Exploration

Consider:

- Hand sanitizer
- Engine biofuel
- Laboratory solvent
- Perfume
- Medical disinfectant

Discuss with a partner:

- Which products might contain alcohol? .....
- Why do some liquids mix easily with water while others do not?.....

Point!

1. Alcohols

(a) Alcohols: Compounds in which a hydrogen atom of a hydrocarbon is substituted with a hydroxyl group − OH. The general formula is R − OH Where are as an alkyle group.

(b) Nomenclature of alcohols: The suffix "-e" of the alkane with the same number of carbon atoms is changed to "-ol" . (Table 4-7-2 the right)

Table 4-7-1 ⟨Examples of alcohols⟩

Name	Condensed structural formula
Methanol	CH_3OH
Ethanol	C_2H_5OH
1-Propanol	$CH_3CH_2CH_2OH$
1-Butanol	$CH_3CH_2CH_2CH_2OH$

structure of science

Key fact :

Alcohols contain a hydroxyl group (−OH), while ethers contain an oxygen atom between two hydrocarbon groups (R−O−R′).

Primary, secondary, and tertiary alcohols undergo different oxidation reactions.

Key concepts:

Functional groups
Alcohol classification
Hydrogen bonding a
Oxidation pattern
Dehydration of ethanol
Alcohol

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(c) Classification of alcohols

(i) An alcohol with 1 hydroxyl group − OH is called a **monohydric alcohol**, one with 2 is called a **dihydric alcohol**, and one with 3 is called a **trihydric alcohol**.

Table 4-7-2 ⟨Classification of alcohols and substance examples⟩

Classification	Substance example	Structure
Monohydric	Methanol	$CH_3 — OH$
	Ethanol	$CH_3 — CH_2 — OH$
Dihydric	Ethylene glycol	$CH_2(OH)—CH_2(OH)$
Trihydric	Glycerin (Glycerol)	$CH_2(OH)—CH(OH)—CH_2(OH)$

(ii) A **primary alcohol** has one other hydrocarbon group attached to the carbon bearing the − OH group; a **secondary alcohol** has two; and a **tertiary alcohol** has three.

Table 4.7.3. solubility of alcohol in water

Primary alcohol	Secondary alcohol	Tertiary alcohol
$R^1—C(H)(H)—OH$	$R^1—C(R^2)(H)—OH$	$R^1—C(R^2)(R^3)—OH$

(d) Reactions of alcohols

(i) Solubility in water: Because the hydroxyl group easily bonds with water molecules, alcohols with a small number of carbon atoms are highly soluble in water.

(ii) Reaction with sodium: When sodium is added to an alcohol, **hydrogen** is generated.

Example: Reaction with Ethanol $2C_2H_5OH + 2Na \longrightarrow \underset{\text{sodium ethanolate}}{2C_2H_5ONa} + H_2$

(iii) Oxidation by oxidising agents: Primary alcohols: Are oxidised to **aldehydes**; further oxidation gives **carboxylic acids**.

Secondary alcohols: Are oxidised to **ketones**.

Tertiary alcohols: Resistant to oxidation.

$$\underset{\text{primary alcohol}}{R—CH_2—OH} \underset{\text{reduction (+2H)}}{\overset{\text{oxidation (−2H)}}{\rightleftharpoons}} \underset{\text{aldehyde}}{R—C(=O)—H} \underset{\text{reduction (−O)}}{\overset{\text{oxidation (+O)}}{\rightleftharpoons}} \underset{\text{carboxylic acid}}{R—C(=O)—OH}$$

$$\underset{\text{secondary alcohol}}{R—CH(OH)—R'} \underset{\text{reduction (+2H)}}{\overset{\text{oxidation (−2H)}}{\rightleftharpoons}} \underset{\text{ketone}}{R—C(=O)—R'}$$

(iv) Dehydration reactions:

- When a mixture of ethanol and concentrated sulfuric acid is heated to 160–170°C, **ethylene** is produced.

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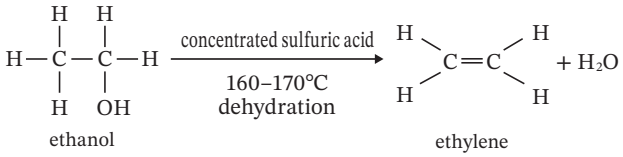
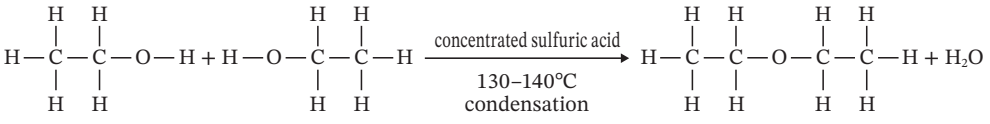


ethanol — ethylene

• When heated to 130–140°C, **diethyl ether** is produced.



ethanol — diethyl ether

Nature of Science

Observation

Three alcohol samples are treated with the same oxidizing agent.

• Sample A forms an aldehyde.

• Sample B forms a ketone.

• Sample C shows almost no reaction.

Inference

What type of alcohol is each sample?.....

Prediction

What products would form if oxidation continued?

.....

2. Ethers

(a) Ethers: Compounds in which the hydrogen atom of the hydroxyl group – OH of an alcohol is substituted with a hydrocarbon group. The general formula is $R^1 - O - R^2$.

(b) Properties of ethers

• There are alcohols that are **structural isomers** of them.

• Their boiling points are **lower** compared to their isomeric alcohols.

• **Poorly soluble** in water, and **do not react** with sodium.

(c) Diethyl ether **$C_2H_5OC_2H_5$**

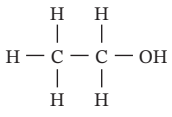
• A colourless, volatile liquid with an **anaesthetic** effect.

• **Dissolves** many organic compounds.

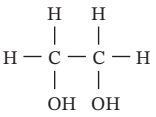
Warm Up

(a) Answer the following questions about substances **A** to **D** below.

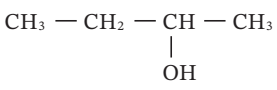
A



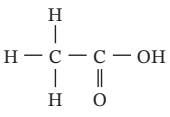
B



C



D



(i) Which of A to D is a secondary alcohol? Select the appropriate letter.

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(ii) Which of A to D is a dihydric alcohol? Select the appropriate letter.

(b) The following statements (i) to (iii) describe either ethanol or diethyl ether. Select all statements that describe diethyl ether.

(i) Generates hydrogen when sodium is added.

(ii) Because it can dissolve many organic compounds, it is used as an organic solvent.

(iii) Poorly soluble in water.

(c) Two test tubes contain ethanol and dimethyl ether, which are represented by the molecular formula C_2H_6O. To distinguish between them, elemental sodium was added to each test tube.

(i) State what change is observed in each test tube.

(ii) Explain why such a difference occurs.

Explanation

(a) (i) Classified into primary alcohols, secondary alcohols, and tertiary alcohols based on the number of other hydrocarbon groups bonded to the carbon atom to which the hydroxyl group − OH is bonded.

In A and B, there is 1 other hydrocarbon group bonded to the carbon to which the hydroxyl group is bonded, so they are primary alcohols. In C, there are 2, so it is a secondary alcohol. D is not an alcohol but a carboxylic acid having a carboxyl group − COOH. Therefore, C.

(ii) Classified into monohydric alcohols, dihydric alcohols, trihydric alcohols, ... based on the number of hydroxyl groups − OH.

A and C have 1 hydroxyl group, so they are monohydric alcohols. B has 2 hydroxyl groups, so it is a dihydric alcohol. Therefore, B.

(b) Ethanol is an alcohol, and diethyl ether is an ether.

(i) It is ethanol, an alcohol, that reacts with sodium.

(ii) Diethyl ether dissolves many organic compounds and is used as an organic solvent.

(iii) Ethanol is highly soluble in water, but diethyl ether is poorly soluble in water.

Therefore, (ii) , (iii) .

(c) (i) Ethanol: Effervescence (hydrogen gas) is observed as the sodium dissolves.

Dimethyl ether: No reaction occurs.

(ii) **Example:** Ethanol contains a hydroxyl group, whereas dimethyl ether has an ether linkage and lacks a hydroxyl group.

Think as an Engineer

Chemical engineers can produce either

• Ethylene • Diethyl ether

from ethanol simply by changing the reaction temperature.

Challenge

Design a process to maximize ethylene production while minimizing ether formation. Which operating temperature would you choose?

Explain your decision.

Try

1. Choose a dihydric alcohol and a tertiary alcohol from the following alcohols A to E, and select the appropriate letters.

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(A) $CH_3 - CH_2 - CH_2 - OH$

(B) $HO - CH_2 - CH_2 - CH_2 - OH$

(C) $HO - CH_2 - \underset{\displaystyle OH}{\underset{|}{CH}} - CH_2 - OH$

(D) $CH_3 - CH_2 - \underset{\displaystyle OH}{\underset{|}{CH}} - CH_3$

(E) $CH_3 - \underset{\displaystyle OH}{\underset{|}{\overset{\displaystyle CH_3}{\overset{|}{C}}}} - CH_3$

2. Fill in the blanks with the appropriate words or numbers in the following text.

Alcohols are classified by the number of (a) atoms bonded to the carbon atom that bears the − OH group. When an alcohol is (b) using potassium dichromate acidified with sulfuric acid, primary alcohols are first converted to (d) and then further to (c), and secondary alcohols produce (e), but tertiary alcohols are not (b). Also, alcohols are classified by the number of (f) groups in the molecule. Methanol is a monohydric alcohol, ethylene glycol is a dihydric alcohol, and glycerin is a trihydric alcohol.

3. Which of the following statements (i) to (iv) describe ethanol? Select all that apply.

(i) Poorly soluble in water.

(ii) Reacts with elemental sodium and generates hydrogen.

(iii) A colourless, volatile liquid with an anaesthetic effect.

(iv) It is a primary alcohol.

Interpreting Data

Questions

• At which temperature is ether production greatest?

.....

• At which temperature is alkene production favored?

.....

• Explain using collision theory and reaction pathways.

.....

Temperature (°C)	Main Product
130	Diethyl ether
140	Mostly diethyl ether
150	Mixture
160	Mostly ethylene
170	Ethylene

Exercise

Choose the correct answer:

1.Which alcohol would most likely produce a ketone when oxidized?

A. Methanol

B. Ethanol

C. Propan-2-ol

D. tert-Butanol

2. An engineer wants to maximize ethylene production from ethanol. Which condition is most appropriate?

A. 120°C

B. 135°C

C. 165°C

D. Room temperature

Answer the following question:

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3. Classify the following alcohols into primary alcohols, secondary alcohols, and tertiary alcohols.

(A) $CH_3 - CH_2 - OH$

(B) $CH_3 - CH_2 - CH_2 - OH$

(C) $CH_3 - \underset{\displaystyle OH}{\underset{|}{CH}} - CH_3$

(D) $CH_3 - \underset{\displaystyle CH_3}{\underset{|}{CH}} - CH_2 - OH$

(E) $CH_3 - CH_2 - \underset{\displaystyle CH_3}{\underset{|}{CH}} - OH$

(F) $CH_3 - \underset{\displaystyle CH_3}{\overset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}} - OH$

4. Fill in the blanks with the appropriate words, compound names, or chemical formulas in the following text.

Compounds with a structure in which hydrogen atoms of a hydrocarbon are replaced by hydroxyl groups are collectively called alcohols. The name of the alcohol with the simplest structure is methanol, its molecular formula is (a), and its condensed structural formula is (b). The name of the alcohol with 2 carbon atoms is (c), and industrially it is synthesized by the addition of water to (d) using phosphoric acid or the like as a catalyst.

There are two types of structures in which a hydrogen atom of propane is substituted with a hydroxyl group: the primary alcohol (e) and the secondary alcohol (f). When a primary alcohol is oxidised with an oxidising agent, it first changes to (g), and upon further oxidation, produces (h).

5. For the following statements I to V, write A if it applies to ethanol, B if it applies to diethyl ether, C if it applies to both, and D if it applies to neither.

I Highly soluble in water.

II A highly flammable, volatile liquid with an anaesthetic effect.

III Acts as an oxidising agent.

IV A colourless liquid at room temperature.

V Does not react with elemental sodium.

Challenge Your Thinking

An unknown compound has the molecular formula C_2H_6O.

Experimental observations:

- It mixes completely with water.
- It reacts with sodium, producing bubbles.
- It does not behave as an ether.

Identify the compound.

Support your answer using structural evidence.

.....

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Lesson 4-8 — Aldehydes and Ketones

Engaging Introduction

Imagine a chemist working in a quality-control laboratory receives two identical bottles containing colorless liquids. One is used to preserve biological specimens, while the other is commonly found in nail polish remover. Although they look almost identical, simple chemical tests reveal that they behave very differently. One forms a brilliant silver mirror inside a test tube, while the other does not react at all.

How can chemists distinguish between compounds that appear so similar? What does their molecular structure reveal about their chemical behavior?

Let's explore how the structures of aldehydes and ketones determine their properties, reactions, laboratory identification, and real-world applications.

Guiding Question How do chemists distinguish between aldehydes and ketones using their chemical reactions?

structure of science

Key fact :

Although aldehydes and ketones both contain a carbonyl group (C=O), the position of this group determines their chemical behavior.

Key concepts:

Aldehydes-Fehling's solution- Ketones-Iodoform Reaction

Exploration

A laboratory receives two unlabeled bottles containing colorless liquids.

Bottle A forms a silver mirror when heated with Tollens' reagent Ammoniacal Silver Nitate aquaus solution.

Bottle B shows no visible change.

Discuss:

- Are the two liquids the same compound? ……
- What evidence would help identify each substance? ……
- Why might one react while the other does not?……

Point!

1. Aldehydes

(a) Aldehydes: Compounds having a formyl group (aldehyde group) . The general formula is R − CHO.

(b) Properties of aldehydes

- Obtained by oxidising **primary alcohols** , and upon further oxidation, become **carboxylic acids** .
- Aldehydes are easily oxidised and exhibit **reducing** properties.

(i) **Silver mirror test**: When an aldehyde is added to an ammoniacal silver nitrate aqueous solution and heated, silver ions Ag^+ are reduced and silver precipitates.

(ii) Reduction of Fehling's solution: When an aldehyde is added to Fehling's solution and heated, copper(II) ions Cu^{2+} are reduced, producing a red precipitate of copper(I) oxide Cu_2O.

Fehling's solution contains Cu^{2+}.

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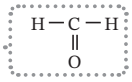
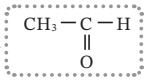
(c) **Various aldehydes**

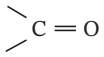
(i) **Formaldehyde** HCHO 

- A colourless, toxic gas with a pungent odour.
- **Highly soluble** in water.
- Obtained by oxidising **methanol** in the air.
- An aqueous solution containing about 37% formaldehyde is called **formalin** , and is used as a preservative solution for animal specimens, etc.

(ii) **Acetaldehyde** CH_3CHO 

- A colourless, toxic liquid with a pungent odour.
- Obtained by oxidising **ethanol** with an acidic sulfuric acid aqueous solution of potassium dichromate.

2. Ketones

(a) Ketones: Compounds in which two hydrocarbon groups are bonded to a carbonyl group  . The general formula is $R^1 - CO - R^2$.

(b) Properties of ketones

- Obtained by oxidising **secondary alcohols** .
- Not easily oxidised and do not exhibit reducing properties.
- There are aldehydes that are structural isomers of them.

(c) Acetone CH_3COCH_3

- A colourless liquid with a pleasant odour.
- Miscible with water in any proportion.
- In the laboratory, it is obtained by the oxidation of 2-propanol or the thermal decomposition of calcium acetate.

(d) Iodoform Reaction

The iodoform reaction occurs when an organic compound with a specific structural unit is heated with iodine (I_2) in an alkaline aqueous solution, producing a yellow precipitate of **iodoform** (CHI_3) with a characteristic color.

Think as an Engineer

Quality-control engineers in a pharmaceutical company must verify whether an alcohol has been completely oxidized during production.

Which laboratory test would you recommend?

- Silver mirror test
- Fehling's test
- Iodoform test

Justify your recommendation using chemical evidence.

.....

Structural Requirements

This reaction is given by compounds that contain **one of the following structural units** in their molecule (where R is a hydrogen atom (H) or a hydrocarbon group):

(i) Compounds with the structure $CH_3 - CO -$ (e.g., Acetaldehyde, Acetone, etc.)

(ii) Compounds with the structure $CH_3 - CH(OH) -$ (e.g., Ethanol, Propan-2-ol, etc.)

Note: Compounds with structure (ii) are oxidized (Oxidation) by iodine during the reaction, converting them into structure (i). Consequently, they give the

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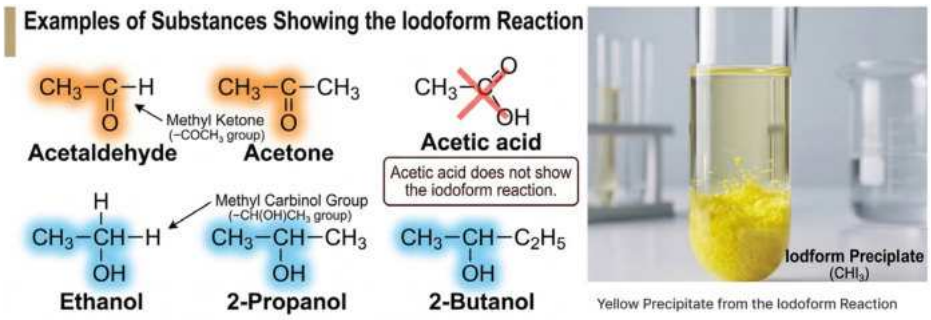
iodoform reaction.



Yellow Precipitate from the Iodoform Reaction

Think Critically

Claim

Aldehydes are reducing agents, while ketones are not.

Evidence

Use results from both laboratory tests.

……

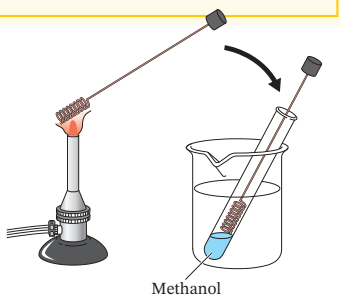
Reasoning

Explain how oxidation state and molecular structure account for the observed differences.

……

Warm Up

(a) Answer the following questions about the experimental procedures and results (I to III) regarding methanol.



(i) Put about 7 mL of methanol into a test tube and warm it in a water bath.

(ii) When a copper wire heated to become copper(II) oxide was brought close to the liquid surface of the methanol, the blackened copper wire part turned red.

III To confirm the product in Experiment II, when an ammoniacal silver nitrate aqueous solution was added, the inner wall of the test tube was covered with a silvery-white substance.

(i) In Experiment II, what did copper(II) oxide change into?

(ii) In Experiment II, what did methanol change into? Name the substance and write its structural formula.

(iii) What characteristics of organic compounds can the operation performed in Experiment III detect?

(b) Answer the following questions about the compounds represented by the molecular formula C_3H_8O.

(i) Among these compounds, name the substance that becomes an aldehyde upon gentle oxidation, and becomes a carboxylic acid upon further oxidation.

(ii) Write the structural formulas of the aldehyde and carboxylic acid produced in (i).

(iii) Among these compounds, name the substance that becomes a ketone upon oxidation.

(iv) Does the compound in (iii) show an iodoform test?

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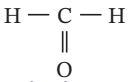
Explanation

(a) (i) Since copper(II) oxide changed to red, it is understood that it changed to copper.
Answer: Copper.

(ii) From (i), since copper(II) oxide was reduced and changed to copper, it is understood that methanol was oxidised. What is obtained by oxidising methanol is formaldehyde.

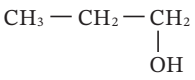
Therefore, Name: Formaldehyde, Structural formula:



(iii) The reaction that occurred in Experiment III is the silver mirror test, in which Ag^+ in the aqueous solution is reduced and silver Ag precipitates. The silver mirror test is a reaction caused by the reducing property of aldehydes, and organic compounds having a formyl group are called aldehydes.

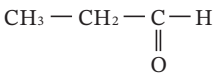
Thus, the silver mirror test detects: organic compounds containing a formyl group (an aldehyde group).

(b) (i) What becomes a carboxylic acid via an aldehyde upon gentle oxidation is a primary alcohol. In a primary alcohol, the hydroxyl group is bonded to the terminal carbon atom, giving the structure shown on the right.

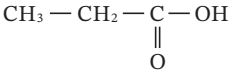


Therefore, the substance is: 1-propanol.

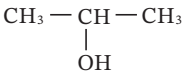
(ii) Aldehyde:



Carboxylic acid:



(iii) What becomes a ketone upon oxidation is a secondary alcohol. In a secondary alcohol, the hydroxyl group is bonded to the central carbon atom, giving the structure shown on the right.



Therefore, the substance is: 2-propanol.

(iv) It shows the reaction.

Interpreting Data

Students analyze the following results

Compound	Silver Mirror	Fehling's	Oxidation Product
Methanal	Yes	Yes	Methanoic acid
Ethanal	Yes	Yes	Ethanoic acid
Propanone	No	No	No reaction

Questions

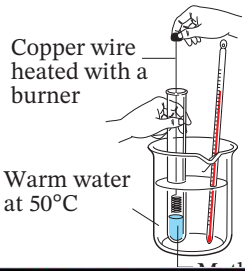
- Which compounds are aldehydes? .....
- Which compound is a ketone? .....
- Which compound is easiest to oxidize? .....
- Explain the pattern.....

Be Global Citizen

Formaldehyde is useful for preserving biological materials, but prolonged exposure may affect human health. Scientists and governments regulate its use in schools, hospitals, and workplaces.

Try

1. Place about 5.0 mL of methanol in a test tube and warm it in 50°C water. After warming, a spiral copper wire heated in the air using a gas burner was brought close to the liquid surface of the methanol while it



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was hot, as shown in the figure, and this operation was repeated 5 to 6 times. Answer the following questions.

(a) What did methanol change into as a result of this procedure? Write the condensed structural formula and name the product.

(b) To confirm the product of **(a)**, an ammoniacal silver nitrate aqueous solution was added. What kind of change occurred? Also, answer the name of the test.

(c) An approximately 37% aqueous solution of the substance produced in the experiment is used for preserving biological specimens. What is this aqueous solution called?

2. Answer the following questions:

(a) Fill in the blanks with the appropriate words in the following text.

Aldehydes are compounds having a (i) group − CHO, and (ii) are compounds having a carbonyl group.

As an experiment to confirm the properties of an aldehyde, there is one where an ammoniacal silver nitrate aqueous solution is added to an aldehyde and heated. This is called the (iii) test. One of the representative aldehydes is (iv), which is obtained by oxidising ethanol with an acidic sulfuric acid aqueous solution of potassium dichromate.

Ketones have representative substances such as acetone. When iodine is added to a basic aqueous solution in which acetone is dissolved and reacted, a yellow precipitate with a characteristic odour is produced. This reaction is called the (v) test.

(b) For the following descriptions, write A if it applies to acetaldehyde, and B if it applies to acetone.

I Produced by the oxidation of a primary alcohol.

II Produced by the oxidation of a secondary alcohol.

III Becomes a carboxylic acid when oxidised.

IV Has reducing properties.

3. Consider compounds A, B, and C represented by the molecular formula C_3H_8O. A and B react with sodium to generate a gas, but C does not. Also, when A and B were gently oxidised, compound D was obtained from A, and compound E was obtained from B. When an ammoniacal silver nitrate aqueous solution was added to D and E, only E showed a test. Answer the following questions.

(a) Write the structural formulas of A to E.

(b) Among A to E, which ones produce a yellow precipitate when iodine and aqueous sodium hydroxide are added and reacted? Select all appropriate letters.

(c) Among A to E, which ones produce a red precipitate when Fehling's solution is added and heated? Select all appropriate letters.

Exercise

Choose the correct answer:

1- A chemist wants to distinguish an aldehyde from a ketone using a simple laboratory test. Which reagent should be used?

A. Bromine water
B. Ammoniacal silver nitrate solution
C. Dilute hydrochloric acid
D. Sodium chloride solution

2.A primary alcohol is gently oxidised. What is the first organic product formed?

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A. Ketone B. Alkene

C. Aldehyde D. Carboxylic acid

Answer the following question:

3. After strongly heating a copper wire with a gas burner, it was immediately brought close to the liquid surface of methanol placed in a test tube, and the copper wire returned to its original colour. By repeating this operation, compound A with a pungent odour was produced. A has ((i) oxidising property / reducing property), and when an aqueous solution containing A is added to Fehling's solution and heated, a ((ii) red / yellow) precipitate of (iii) (Cu_2O / CHI_3) is formed. Also, when added to an ammoniacal silver nitrate aqueous solution and warmed, the (iv) test is observed. Answer the following questions.

(a) Choose the appropriate words or chemical formulas for the blanks (i) to (iii) in the text from the options in parentheses.

(b) Provide the word corresponding to (iv).

(c) In the underlined part, why did the copper wire return to its original colour? Explain using all the following words. [Word group: Reduction, Copper(II) oxide, Copper, Methanol]

4. Answer the following questions.

(a) Fill in the blanks with the appropriate words or compound names in the following text.

When a primary alcohol is oxidised with an oxidising agent, it first changes to a (i), and upon further oxidation, produces a (ii). Also, when a secondary alcohol is oxidised, it changes to a (iii). For example, by oxidising 2-propanol with an oxidising agent, it becomes (iv), which is a kind of (iii).

(b) For formaldehyde and acetone, write A if the following properties (i) to (v) apply only to formaldehyde, B if they apply only to acetone, and C if they apply to both in common.

(i) Has the structure − CO −. (ii) Reduces Fehling's solution.

(iii) Shows the iodoform test. (iv) Becomes a carboxylic acid when oxidised.

(v) Becomes a secondary alcohol when reduced.

5. Consider 3 types of compounds, A to C, represented by the molecular formula C_3H_8O. A and B are alcohols, and C is an isomer of A and B. D is obtained by the oxidation of A, or by the thermal decomposition of calcium acetate without air. E shows a reducing property and is obtained by the oxidation of B, but when E is further oxidised, it becomes F, which is a weak acid. Answer the following questions.

(a) Name compounds A, B, and D.

(b) Write the structural formulas of compounds C and E.

(c) Among compounds A to F, how many show the iodoform test?

Challenge Your Thinking

A chemist performs the following tests on an unknown compound.

- Positive Tollens' test
- Positive Fehling's test
- Negative Iodoform test

Predict:

- Which functional group is present? .....
- Suggest one possible compound. .....
- Explain your reasoning using evidence .....

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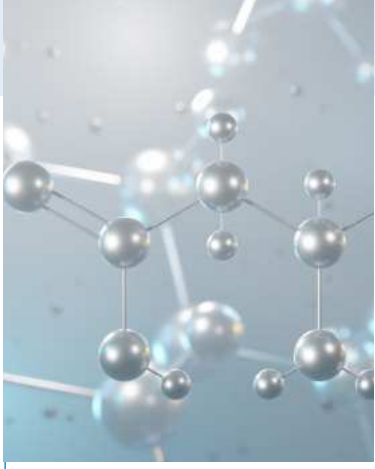
Lesson 4-9 — Carboxylic Acids



Engaging Introduction

Think about the sharp smell of vinegar in your kitchen. Why does it taste sour, while alcohol has a completely different taste and behavior, even though both contain carbon, hydrogen, and oxygen?

Now imagine that two medicines contain the same atoms arranged in almost the same way, yet one works effectively in the human body while the other has a completely different biological effect.

In this lesson, let's explore how the structure of carboxylic acids and the three-dimensional arrangement of molecules determine their chemical reactions and their importance in biology, medicine, and everyday life.

Guiding Question How does molecular structure determine the chemical properties, biological activity, and practical applications of carboxylic acids and their isomers?

Point!

1. Carboxylic Acids

(a) Carboxylic acids: Compounds having a carboxyl group − COOH. The general formula is R − COOH.

(b) Classification of carboxylic acids

A carboxylic acid with 1 carboxyl group − COOH is called a **monocarboxylic acid**, and one with 2 is called a **dicarboxylic acid**.

(c) **Fatty acids**: Long-chain monocarboxylic acids.

- **Higher fatty acids**: Fatty acids with a large number of carbon atoms.
- **Lower fatty acids**: Fatty acids with a small number of carbon atoms.

(d) Properties of carboxylic acids

- Obtained by the oxidation of **primary alcohols** and **aldehydes**.
- Aqueous solutions are **weakly acidic**.
- Their acid strength is **stronger** than carbonic acid, and they react with sodium hydrogen carbonate to generate **carbon dioxide**.

Example: $CH_3COOH + NaHCO_3 \longrightarrow CH_3COONa + H_2O + CO_2$

Inquiry-Based Learning

A student has two colorless liquids:

- Vinegar
- Ethanol

Both look identical.

How could you identify which one is the carboxylic acid using only sodium hydrogen carbonate?

.....

Predict your observations before reading the explanation?

.....

Structure of Science

Key fact :

Carboxylic acids are organic compounds that contain the carboxyl functional group (–COOH).

Enantiomers are stereoisomers that are non-superimposable mirror images of each other.

Fatty acids are open-chain monocarboxylic acids..

Key Concepts

- Fatty acids

Functional groups

Carboxylic acids

Hydroxy acids

Geometric (cis–trans) isomerism

Stereoisomerism

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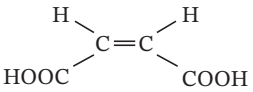
(e) Various carboxylic acids

(i) Formic acid **HCOOH**: A colourless, toxic liquid with a pungent odour. Has the structure of a formyl group.

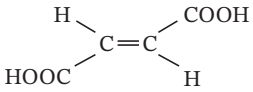
(ii) Acetic acid **CH_3COOH**: A colourless liquid with a pungent odour. Contained in vinegar at 4–5%.

(iii) Maleic acid, Fumaric acid: Dicarboxylic acids that are cis-trans isomers of each other.

- **Maleic acid** dehydrates when heated. **Fumaric acid** is difficult to dehydrate.



Maleic acid (cis isomer)



Fumaric acid (trans isomer)

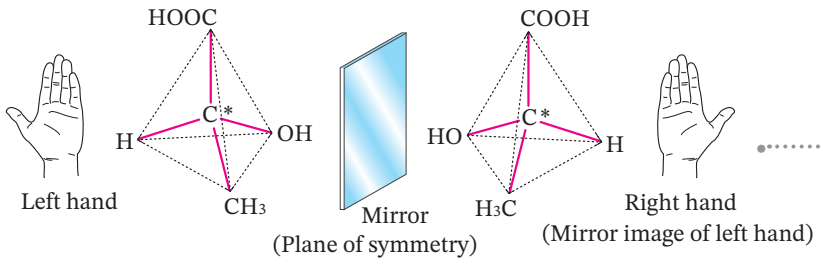
(iv) **Hydroxy acids**: Carboxylic acids having a hydroxyl group − OH. Show properties of both alcohols and carboxylic acids. **Example:** Lactic acid CH_3CH (OH) COOH

2. Enantiomers (Optical Isomers)

(a) **Chiral carbon atom**: A carbon atom to which 4 different types of atoms or groups of atoms are bonded.

(b) **Enantiomers**: Stereoisomers that arise due to having a chiral carbon atom. They have a relationship of a real image and a mirror image, like left and right hands.

⟨Enantiomers of lactic acid⟩



Chiral carbon atoms are often represented with an asterisk (*).

Think Critically

Claim

Enantiomers can have identical physical properties but different biological effects.

Evidence

- Same melting point
- Same density
- Different optical activity
- Different physiological responses

Reasoning

Biological receptors are three-dimensional and recognize molecular shape rather than molecular formula.

(c) Properties of enantiomers

- Properties such as melting point and density are the same.
- They differ in optical activity (rotation of plane-polarised light) and in physiological effects such as taste.

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Life Application

Why Does Vinegar Remove Lime scale?

Vinegar contains acetic acid, a weak acid that reacts with calcium carbonate deposits (limescale), producing carbon dioxide gas and soluble salts.

Warm Up

Answer the following questions.

(a) Select the letter of the most appropriate word for each blank.

(i) ( ) reacts with sodium hydrogen carbonate to generate carbon dioxide.

(A) Formic acid **(B)** Acetone **(C)** Ethanol **(D)** Ethyl methyl ether

(ii) Carboxylic acids are produced by the oxidation of ( ).

(A) Secondary alcohol **(B)** Ketone **(C)** Aldehyde **(D)** Ester

(iii) The dicarboxylic acid that dehydrates when heated is ( ).

(A) Acetic acid **(B)** Maleic acid **(C)** Lactic acid **(D)** Fumaric acid

(b) From A to C, select the structure that has a chiral carbon atom (and therefore exists as enantiomers).

(A) $CH_3-\underset{\underset{OH}{|}}{CH}-CH_3$ **(B)** $CH_3-CH_2-\underset{\underset{O}{\|}}{C}-CH_3$ **(C)** $CH_3-CH_2-\underset{\underset{OH}{|}}{CH}-CH_3$

Explanation

(a) (i) It is carboxylic acids that react with sodium hydrogen carbonate to generate carbon dioxide. Among the choices, only formic acid is a carboxylic acid. Answer: A.

(ii) C (iii) B

(b) For a chiral carbon atom, the ends of the 4 bonds extending from C are all different atoms or groups of atoms.

If the structural formulas of A to C are rewritten so that the bonds of C are easy to understand, they become as follows:

A

$$CH_3-\underset{\underset{OH}{|}}{\overset{\overset{H}{|}}{C}}-CH_3$$

B

$$CH_3-CH_2-\underset{\underset{O}{\|}}{C}-CH_3$$

C

$$CH_3-CH_2-\underset{\underset{OH}{|}}{\overset{\overset{H}{|}}{C}}-CH_3$$

In A , two $-CH_3$ groups are bonded.

B has a double bond, so 4 different types are not bonded.

In C, 4 different groups ($-C_2H_5$, $-CH_3$, $-H$, $-OH$) are bonded.

Therefore, C.

Interpreting Data

Suppose the following experimental observations were recorded.

Compound	Dehydrates when Heated?
Maleic acid	Yes
Fumaric acid	No

Questions

- What conclusion can you draw about the effect of molecular arrangement on chemical reactions?

.....

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Try

1. Read the following text and answer the questions below.

(i) is the main component of vinegar, and is obtained by oxidising (ii) which has a formyl group. (i) is a colourless liquid with a pungent odour, its aqueous solution is (iii), and its strength is (iv) than carbonic acid.

(a) Fill in the blanks with the appropriate substance names and words in the text.

(b) Under which of the following conditions is a chemical change observed? Select the appropriate letter, and name the gas generated.

A Mix sodium acetate and carbonated water.

B Add acetic acid to an aqueous sodium hydrogen carbonate solution.

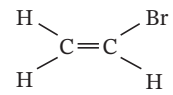
2. Fill in the blanks (i) to (vi) with the appropriate words in the following text. Also, choose the compounds A to E from the word bank below and write their structural formulas.

A, B, and C are open-chain (i) monocarboxylic acids. A shows a silver mirror reaction, but B and C do not. Also, C has a carboxyl group and a (ii) group in its molecule, and is a (iii) acid contained in yogurt, etc. Furthermore, C has one chiral carbon atom in its molecule, and (iv) isomers exist. On the other hand, D and E are open-chain (v) dicarboxylic acids. D and E are (vi) isomers of each other, and when D is heated, it undergoes dehydration to produce an acid anhydride, but such a change does not occur in E.

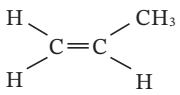
[Word group] Formic acid Maleic acid Acetic acid Fumaric acid Lactic acid

3. Which of the compounds **A** to **D** below yield a product with two chiral carbon atoms when iodine I_2 is added? Select all that apply.

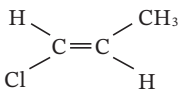
A



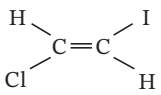
B



C



D



Exercise

Choose the correct answer:

1. A student adds sodium hydrogen carbonate to an unknown liquid. Gas bubbles are produced immediately. Which functional group is most likely present?

A. Hydroxyl group

B. Carboxyl group

C. Carbonyl group

D. Ether linkage

2. A bottle of vinegar is tested in the laboratory. Which carboxylic acid is mainly responsible for its acidic properties?

A. Formic acid

B. Acetic acid

C. Lactic acid

D. Fumaric acid

Answer the following question:

Chemistry in Society

Carboxylic acids and chiral molecules are essential in:

- Food preservation
- Medicine
- Biotechnology
- Agriculture
- Polymer production
- Sustainable chemical manufacturing

Understanding molecular structure allows scientists to design safer medicines, improve food quality, and develop environmentally friendly materials.

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3. Choose the appropriate words corresponding to the blanks (i) to (v) in the text.

A compound having ((i) − CHO / − COOH) in the molecule is called a carboxylic acid. Acetic acid is a kind of carboxylic acid, its aqueous solution shows ((ii) basicity / acidity), and its strength is ((iii) stronger / weaker) than an aqueous solution of carbon dioxide (carbonic acid). Therefore, when ((iv) sodium hydrogen carbonate / sodium) is added to acetic acid, ((v) oxygen / carbon dioxide) is generated.

4. Read the following text and answer the questions below.

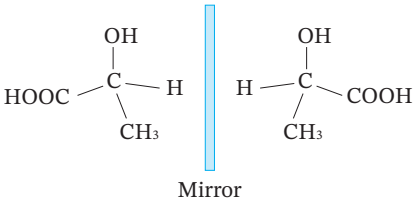
Because A contains a (i) group as well as a carboxyl group, it shows a (ii) property. This is why when A is added to an ammoniacal silver nitrate aqueous solution, (iii) precipitates.

Also, among unsaturated dicarboxylic acids with 4 carbon atoms, there are (iv) in the cis form and (v) in the trans form, which are cis-trans isomers of each other.

(a) Fill in the blanks with the appropriate words.

(b) Write the structural formulas of compounds A, (iv), and (v).

5. The figure on the right shows the isomers of lactic acid. Read the following text about lactic acid and answer the questions below.

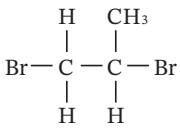


When a carbon atom is attached to four different atoms or groups of atoms, as seen in lactic acid, it is called an (i), and a pair of (ii) isomers exist. These (ii) isomers share almost identical melting points, densities, and general chemical properties, but they differ in their optical activity.

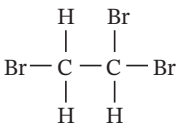
(a) Fill in the blanks with the appropriate words.

(b) Among the following A to D, identify which molecules have zero, one, and two chiral carbon atoms.

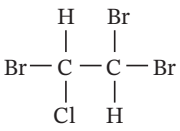
A



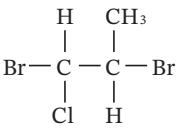
B



C



D



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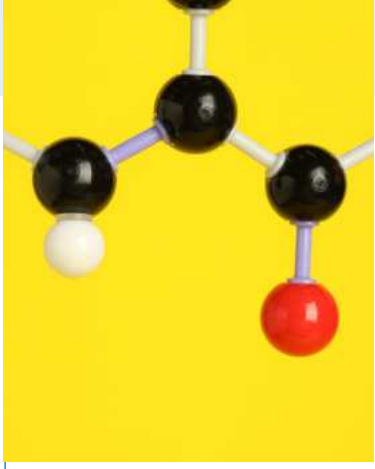
Lesson 4-10 — Esters



Engaging Introduction

Imagine walking into a bakery and noticing the pleasant smell of fresh pastries. Later that day, you peel an orange and enjoy its refreshing aroma. Surprisingly, many of these familiar scents come from the same family of compounds—esters.

These compounds are not only responsible for the fragrances of fruits and flowers but are also used in perfumes, paints, medicines, and even food flavorings.

In this lesson, we will explore how esters are formed, why they have unique properties, and how chemists use them in everyday life and industry.

Guiding Question How can one type of chemical reaction create substances that are useful in food, medicine, fragrances, and manufacturing?

Exploration

Observe the following products:

- Perfume
- Banana flavoring
- Nail polish remover
- Paint thinner

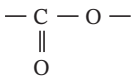
Discuss with a partner:

- What do these products have in common? .....
- Why do many pleasant smells come from similar types of molecules? .....
- How might chemists design compounds with different fragrances? .....

Point!

Esters

(a) **Ester**: A compound having an ester linkage.

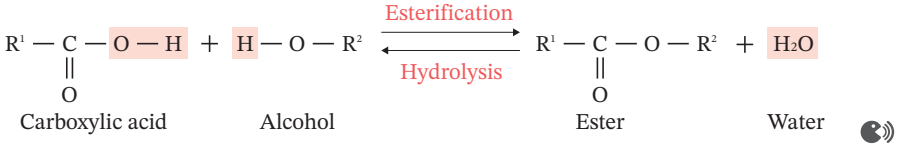


(b) Properties of esters

- Generally, **poorly soluble** in water and **soluble** in organic solvents.
- Esters with small molecular weights have a **fruity** fragrance.
- Used as fragrances and solvents.

(c) **Esterification**: A reaction in which a water molecule is removed from a carboxylic acid and an alcohol to produce an ester.

(d) **Hydrolysis**: The reverse reaction of esterification. When an ester is heated with dilute hydrochloric acid or dilute sulfuric acid, a carboxylic acid and an alcohol are produced.



structure of science

Key fact :

- Esters are responsible for many natural fruit aromas.
- Most esters are poorly soluble in water.
- Esterification is reversible.

Key concepts:

- Ester linkage
- Condensation reaction
- Hydrolysis
- Saponification
- Organic synthesis

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Think Like a Chemist

Predict what will happen if:

- excess water is added
- concentrated sulfuric acid is removed
- the mixture is heated for a longer time

Explain your reasoning

……

(e) Mechanism of Esterification

Esterification was carried out using a carboxylic acid ($R^1 - COOH$) and an alcohol ($R^2 - {}^{18}OH$) enriched with the oxygen isotope ^{18}O (mass number 18). It was determined that the ^{18}O was incorporated into the resulting ester. This result indicates that the OH group is eliminated from the carboxylic acid and the H atom is eliminated from the alcohol to form water (H_2O). In this manner, the reaction mechanism was elucidated using an oxygen isotope.

(f) Various esters

(i) **Methyl acetate** CH_3COOCH_3

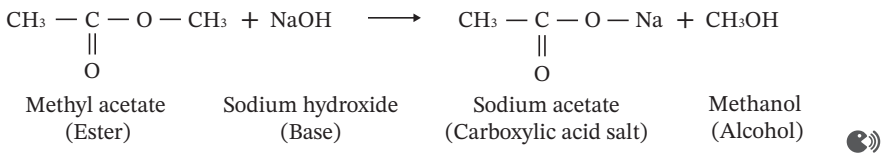
- Produced by the esterification of acetic acid and **methanol** .
- A colourless liquid, **poorly soluble** in water.

(ii) **Ethyl acetate** $CH_3COOC_2H_5$

- Produced by the esterification of acetic acid and **ethanol** .
- A colourless liquid, **poorly soluble** in water.
- Used as a solvent for paints and as a fragrance.

(g) **Saponification**: Hydrolysis of an ester by a base. Produces a carboxylic acid salt and an alcohol.

Example: When an aqueous sodium hydroxide solution is added to methyl acetate and heated, sodium acetate and methanol are produced.


CH₃ — C — O — CH₃ + NaOH ⟶ CH₃ — C — O — Na + CH₃OH
O
O
Methyl acetate (Ester)
Sodium hydroxide (Base)
Sodium acetate (Carboxylic acid salt)
Methanol (Alcohol)

Life Application

Chemists design synthetic esters with different molecular structures to control:

- fragrance intensity
- evaporation rate
- stability
- cost

This is why perfumes, cosmetics, shampoos, and air fresheners often contain specially designed esters.

Warm Up

Answer the following questions about the esters A, B, and C represented by the molecular formula $C_4H_8O_2$.

(a) When ester A was hydrolysed, an alcohol with a boiling point of 78°C and acetic acid were obtained. Write the structural formula and name of ester A.

(b) When the carboxylic acid obtained by hydrolysing ester B was added to a test tube containing an ammoniacal silver nitrate aqueous solution, silver precipitated on the inner wall of the test tube. Also, when the alcohol obtained from B was oxidised, a

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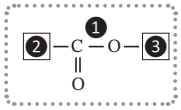
ketone was produced. Write the structural formula of ester B.

(c) When the alcohol obtained by hydrolysing ester C was oxidised, formaldehyde was produced. Also, when the obtained carboxylic acid was added to a test tube containing an ammoniacal silver nitrate aqueous solution, silver did not precipitate. Write the structural formula of ester C.

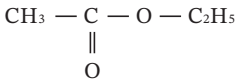
Explanation

(a) ❶ Write the ester bond.



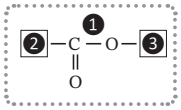
❷ Since the carboxylic acid is acetic acid CH_3COOH, the structure excluding the carboxyl group is CH_3.

❸ The alcohol with a boiling point of 78°C is ethanol. For ethanol C_2H_5OH, the structure excluding the hydroxyl group is C_2H_5. Also, what produces ethanol and acetic acid upon hydrolysis is ethyl acetate.



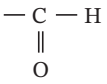
Ethyl acetate is produced by the esterification of ethanol and acetic acid.

Name: Ethyl acetate.



(b) ❶ Write the ester bond.

❷ Since the carboxylic acid obtained by hydrolysis showed a silver mirror reaction, it is understood that it has a formyl group. Therefore, since the structural formula of the carboxylic

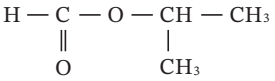


acid is understood to be , the structure excluding the carboxyl group is H.

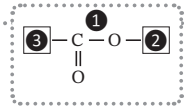
❸ Since the molecular formula is $C_4H_8O_2$, what connects to the oxygen atom is C_3H_7.

Since the alcohol obtained from B produced a ketone when oxidised, it is understood to be a secondary alcohol. Therefore, the hydroxyl group is originally bonded to the central carbon atom among the three.

Therefore, the desired structural formula is .



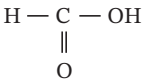
(c) ❶ Write the ester bond.



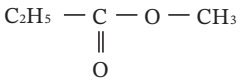
❷ Since the structure of the carboxylic acid is not determined, consider from the alcohol.

Since oxidising the alcohol obtained by hydrolysis produced formaldehyde, it is understood to be methanol CH_3OH. Therefore, the structure excluding the hydroxyl group is CH_3.

❸ Since the molecular formula is $C_4H_8O_2$, what connects to the carbon atom is C_2H_5.



This structure also applies to the fact that it does not show a silver mirror reaction.



Therefore, the desired structural formula is .

Interpreting Data

Compound	Water Solubility	Fruity Odor	Reacts with NaOH
Ethanol	High	No	No
Ethyl acetate	Low	Yes	Yes
Acetic acid	High	No	Yes

Questions

- Which compound is most likely the ester? .....
- Explain your answer using the data? .....

Sustainability Connection

Soap production illustrates one of chemistry's most important industrial reactions.

Modern industries aim to:

- reduce waste
- recycle raw materials
- replace hazardous solvents
- improve energy efficiency.

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Try

1. Read the following text and answer the questions below.

A compound produced by removing a (a) molecule from a (b) group of a carboxylic acid and a (c) group of an alcohol is called an (d). For example, when a small amount of concentrated sulfuric acid is added to a mixture of acetic acid and ethanol and warmed, an (d) called (e) is produced. Such a reaction is called (f). Low molecular weight (d) compounds are volatile liquids with a (g)-like fragrance, and are highly soluble in { h water · organic solvents }.

(i) Fill in the blanks with the appropriate words or substance names in the text. Also, choose the correct one for { }.

(ii) Write a chemical equation for the reaction in the underlined part.

(iii) Write a chemical equation for the reaction that occurs when an aqueous sodium hydroxide solution is added to (e) and heated.

2. When an aqueous sodium hydroxide solution was added to ester A represented by the molecular formula $C_5H_{10}O_2$ and heated, and an acid was added to neutralize it, carboxylic acid B and alcohol C were obtained. Alcohol C is not easily oxidised. Carboxylic acid B is a colourless liquid and showed a reaction with an ammoniacal silver nitrate aqueous solution. Write the structural formula for A, and the structural formulas and names for B and C.

Think Critically

Claim

The oxygen atom in the ester originates from the alcohol

Evidence

The oxygen-18 isotope was detected in the ester product.

Reasoning

Your Reasoning is .....

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Exercise

Choose the correct answer:

1- Why is esterification considered a condensation reaction?

A. It produces oxygen.
B. It removes water.
C. It forms carbon dioxide.
D. It breaks double bonds.

2. Which reaction is the reverse of esterification?

A. Combustion
B. Oxidation
C. Hydrolysis
D. Polymerization

Read the following text and answer the questions below.

3. When a small amount of concentrated sulfuric acid is added to a mixture of acetic acid and methanol and warmed, (a) is produced. This reaction is called (b) , and the oxygen atom of the water produced in the reaction is from acetic acid. (a) is lighter than water, is a liquid that is (c) in water, and has a fragrance.

(i) Fill in the blanks a to c with the appropriate words in the text.

(ii) Write a chemical equation for the reaction in the underlined part.

(iii) Name all substances produced when hydrochloric acid is added to (a) and heated. Also, name this reaction.

(iv) Write a chemical equation for the reaction that occurs when an aqueous sodium hydroxide solution is added to (a) and heated. Also, name this reaction.

……

4. Consider esters A to C represented by the molecular formula $C_5H_{10}O_2$. When they were hydrolysed, A became propionic acid and ethanol, and B became acetic acid and alcohol D. When an aqueous potassium dichromate solution was added to alcohol D, a ketone was produced. C became 2-butanol and carboxylic acid E, and E reacted with an ammoniacal silver nitrate aqueous solution. Answer the following questions.

(a) Write the structural formulas of the compounds A to E.

(b) Which of the compounds A to D show reducing properties? Select all appropriate letters.

(c) Which of the compounds A to E contain a chiral carbon atom? Select all appropriate letters.

……

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Lesson 4-11 — Fats and Oils / Soap

Engaging Introduction

Imagine washing greasy dishes with only water. No matter how much you rinse, the grease remains stuck to the surface. However, the moment you add a small amount of dish soap, the grease suddenly disappears.

Now think about another everyday observation. Why is olive oil liquid at room temperature while butter remains solid, even though both are made from fats?

In this lesson, we will explore the chemistry of fats, oils, and soap, and discover how molecular structure determines their properties, uses, and importance in everyday life.

Guiding Question How does the molecular structure of fats, oils, and soaps determine their physical properties, biological roles, and industrial applications?

Exploration

Place a drop of cooking oil into a glass of water. No matter how long you wait, the oil forms a separate layer. Now add a few drops of liquid soap and gently stir. The oil breaks into tiny droplets and spreads throughout the water.

- Why does soap succeed where water fails? .....
- What is happening at the molecular level? .....

Point!

1. Fats and Oils

(a) **Fats and oils**: Esters of long-chain fatty acids and glycerin.

(b) **Classification of fats and oils**:

(i) Fat: Fats and oils that are solid at room temperature.

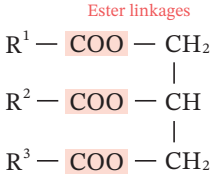
(ii) Fatty oil: Fats and oils that are liquid at room temperature.

- Drying oil: Fatty oils that are easily oxidised and solidify in the air.
- Hardened oil (Hydrogenated oil): Fatty oils made solid by adding hydrogen.

(c) **Structure and molecular weight of fats and oils**:

- One molecule of fat or oil contains 3 ester linkages. (Figure on the right).
- Molecular weight of fat/oil = **Sum of the molecular weights of 3 long-chain fatty acids + 38 Where 38 represents molecular weight of Gyserol -3H2O molecules**

⟨Structure of fats and oils⟩



Think as an Engineer

Food manufacturers often hydrogenate vegetable oils to improve shelf life.

What engineering advantages does hydrogenation provide? .....

What health trade-offs should engineers consider? .....

(d) **Saponification value and Iodine value**:

(i) Saponification value: The numerical value of the mass [mg] of potassium hydroxide

Structure of Science

Key Fact :

- Every fat molecule contains **three ester bonds**.
- Saturated fats contain **no C=C bonds**.
- Unsaturated fats contain **one or more C=C bonds**.

Key Concepts:

- Triglyceride
- Ester linkage
- Saturated fatty acid
- Unsaturated fatty acid
- Hydrogenation
- Saponification value
- Iodine value

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KOH (formula weight 56) required to saponify 1 g of fat or oil.

The amount of potassium hydroxide KOH required to saponify 1 mol of fat or oil is 3 mol.

One KOH is required per one ester bond.

Therefore, if the average molecular weight of the fat or oil is M, Saponification value = $\frac{1}{M} \times 3 \times 56 \times 10^3$

(ii) **Iodine value:** The numerical value of the mass [g] of iodine I2 (molecular weight 254) that can be added to 100 g of fat or oil.

Iodine I_2 can be added as much as the number of **double bonds** between carbon atoms.

If the average molecular weight of the fat or oil is M and the number of double bonds between carbon atoms in one molecule is n, $\frac{1}{M} \times n \times 254$

Investigation

Investigate different cooking oils available at home.

Research:

- Which contain mostly saturated fats?.....
- Which contain unsaturated fats? .....
- Which are hydrogenated? .....

Predict which would have the highest iodine value.

Table 4-11-1: Fatty Acid Composition of Fats and Oils (wt%, per 100g edible portion)

fatty acid composition		Saturated Fatty Acids		Unsaturated Fatty Acids		
		Palmitic Acid	Stearic Acid	Oleic Acid	Linoleic Acid	Linolenic Acid
Chemical Formula		$C_{15}H_{31}-COOH$	$C_{17}H_{35}-COOH$	$C_{17}H_{33}-COOH$	$C_{17}H_{31}-COOH$	$C_{17}H_{29}-COOH$
Melting Point		63°C	71°C	13°C	−5°C	−11°C
Number of C = C Bonds		0	0	1	2	3
Fatty Oil	Sunflower Oil	6.2	4.2	20.2	66.9	0.3
	Soybean Oil	9.9	4	22	50	6.1
Fat	Beef Tallow	23	14	41	3.3	0.2

Data Interpretation Activity

Study the fatty acid composition table.

Which oil would you predict has:

- the highest iodine value?
- the lowest melting point?
- the greatest resistance to oxidation?

Support your conclusions using the data.

.....

2. Soap

(a) **Soap**: A sodium salt of a long-chain fatty acid, RCOONa, obtained by saponifying fats and oils with an aqueous sodium hydroxide solution.

(b) **Structure of soap**: Consists of a hydrophobic group (lipophilic group), which is a hydrocarbon group R −, and a hydrophilic group, − COO−. (Figure 4-11-1 on the right).

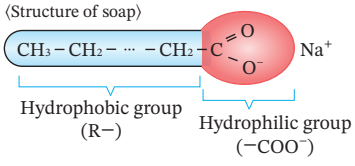

figure 4-11-1- ⟨Structure of soap

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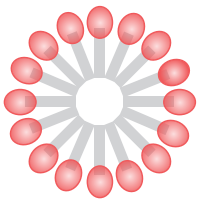
(c) **Surfactant**: A substance that has both a hydrophobic group and a hydrophilic group, like soap. They line up on the surface of water and lower its surface tension.

(d) **Emulsifying action**: The action in which the hydrophobic part of soap surrounds oil and disperses it in water.

(e) **Properties of soap**:

- Its aqueous solution is **weakly basic** .
- When the concentration in an aqueous solution exceeds a certain level, ions gather to form colloidal particles. These colloidal particles are called **micelles** . Figure 4-11-2 on the right
- In **hard water** containing a lot of Ca^{2} + and Mg^{2+}, it forms slightly soluble salts and loses its cleaning power.

〈Micelle〉



They line up with the hydrophobic group on the **inside** and the hydrophilic group on the **outside** .

Figure 4-11-2 〈Micelle〉

(f) **Synthetic detergent**: An artificially synthesized surfactant. Its aqueous solution is neutral, and it maintains its cleaning power even in hard water.

Life application

Warm water reduces the viscosity of oils and fats, making them easier for soap molecules to surround and remove. This is why greasy dishes are usually easier to clean with warm water than with cold water.

Warm Up

Answer the following questions.

(a) Answer the following questions about a fat/oil consisting of 2 molecules of oleic acid $C_{17}H_{33}COOH$ (relative molecular mass 282) and 1 molecule of palmitic acid $C_{15}H_{31}COOH$ (relative molecular mass 256) per molecule of fat/oil. (I_2 = 254, KOH = 56)

(i) Calculate the saponification value to the nearest integer.

(ii) Calculate the iodine value to three significant figures.

(b) Fill in the blanks with the appropriate words in the following text. When an aqueous sodium hydroxide solution is added to fat/oil and heated, it is (**A**), producing (**B**) and a sodium salt of a long-chain fatty acid. This sodium salt is called (**C**). (**C**) consists of a hydrophobic hydrocarbon group and a hydrophilic group of atoms. When (**C**) is dissolved in water, it forms colloidal particles with the hydrophobic part on the (**D**) side and the hydrophilic part on the (**E**) side. This is called a (**F**). When oil and (**C**) water are added and shaken well, the oil becomes fine droplets and disperses in water, forming an emulsion. Such an action of (**C**) is called an (**G**) action, and this is why oil stains are removed. Because (**C**) is a salt of a weak acid and a strong base, it partially hydrolyses in an aqueous solution, and the aqueous solution is (**H**).

(c) When soap is used in hard water, it does not lather well and its cleaning effectiveness decreases. Briefly explain the reason for this.

Explanation

(a) (i) Since Relative molecular mass of fat/oil = Sum of relative molecular masses of 3 long-chain fatty acids +38, the relative molecular mass is:

$282 \times 2 + 256 + 38 = 858$

Since Saponification value = $\frac{1}{M} \times 3 \times 56 \times 10^{3}$ (*M:* average molecular mass), the

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saponification value is:

$\frac{1}{858} \times 3 \times 56 \times 10^3 = 195.8 \approx 196.$ Answer: 196

(ii) Iodine value = $\frac{100}{M} \times n \times 254$ (*M:* average molecular mass, *n*: number of double bonds)

When R of a long-chain fatty acid R − COOH has only single bonds, it is represented as $C_nH_{2n+1}COOH$.

For 15 carbon atoms, it is $C_{15}H_{31}COOH$, so palmitic acid has no double bonds. For 17 carbon atoms, it is $C_{17}H_{35}COOH$, so oleic acid has 2 fewer H atoms, meaning it has 1 double bond. Therefore, there are 2 double bonds per molecule of the fat/oil.

Therefore, the iodine value is:

$\frac{100}{858} \times 2 \times 254 = 59.20 \approx 59.2.$ Answer: 59.2

(b) **(A)** Saponification **(B)** Glycerin **(C)** Soap **(D)** Inside **(E)** Outside **(F)** Micelle **(G)** Emulsifying **(H)** Weakly basic

(c) Soap reacts with calcium ions (Ca^{2+}) and magnesium ions (Mg^{2+}) present in hard water to form an insoluble precipitate called "scum" (metallic soap). Because the soap molecules are consumed to form this precipitate, they cannot function to lower the surface tension and remove dirt, resulting in poor lathering and reduced cleaning power.

Try

1. The mass [mg] of potassium hydroxide required to saponify 1 g of fat/oil is called the saponification value, and the mass [g] of iodine that adds to 100 g of fat/oil is called the iodine value. Answer the following questions.
(C = 12, H = 1.0, O = 16, K = 39, I = 127)

(a) A certain fat/oil has a structure in which 1 molecule each of stearic acid $C_{17}H_{35}COOH$, linoleic acid $C_{17}H_{31}COOH$, and linolenic acid $C_{17}H_{29}COOH$ are esterified to 1 molecule of glycerin. Find the molecular weight of this fat/oil.

(b) Calculate the saponification value of this fat/oil to the nearest integer.

(c) Calculate the iodine value of this fat/oil to three significant figures.

(d) Write one possible structure for this fat/oil using a structural formula.

2. Fill in the blanks with the appropriate words in the following text.

When fat/oil is saponified with an aqueous sodium hydroxide solution, a sodium salt of a long-chain fatty acid is obtained. This is (**A**), and its aqueous solution is weakly (B) due to hydrolysis. (**A**) has a (**C**) hydrocarbon group and a hydrophilic − COO^-, and gathers in an aqueous solution with the hydrocarbon groups on the (**D**) side. Oil attached to fibers is taken into this (**D**) side and becomes easier to disperse in water. This is called an (**E**) action. However, in (**F**) water with a lot of Ca^{2+} or Mg^{2+}, slightly soluble salts are produced, and the cleaning power decreases. Therefore, in synthetic detergents, salts consisting of strong acids and strong bases, such as sodium alkylbenzenesulfonate, are used.
Also, this aqueous solution is (**G**).

⚠ Misconception Alert

Common Misconception:

More soap does not always produce better cleaning.

In hard water, much of the soap reacts with calcium and magnesium ions before it can remove grease.

Be Global Citizen

Modern detergent manufacturers develop biodegradable surfactants that break down more easily in the environment, reducing water pollution and protecting aquatic ecosystems.
Green chemistry aims to design cleaning products that are both effective and environmentally friendly.

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Exercise

Choose the Correct Answer

1. Which fat would most likely have the highest iodine value?
   (a) A fat containing only saturated fatty acids
   (b) A fat containing one double bond
   (c) A fat containing several double bonds
   (d) A hydrogenated fat
2. Which statement about saponification value is correct?
   (a) It increases as molecular mass increases.
   (b) It depends only on the number of double bonds.
   (c) It is higher for fats with lower molecular mass.
   (d) It measures the acidity of fats.

3. Answer the following questions about a fat/oil whose constituent fatty acid is only oleic acid $C_{17}H_{33}COOH$ (relative molecular mass 282) (I_2 = 254, KOH = 56)
   (a) Calculate the saponification value to the nearest integer.....
   (b) Calculate the iodine value to three significant figures.....
   (c) Write a possible structure for this fat/oil using a structural formula.....

4. Read the following text, choose the appropriate words for the blanks (i) to (viii) in the text from the options A to L below, and select the appropriate letters.

Fats and oils are important as food components, and together with carbohydrates and proteins, they are called the three major nutrients. Among fats and oils, those that are solid at room temperature are called (i), and those that are liquid at room temperature are called fatty oils. Among fatty oils, those containing many unsaturated fatty acids that easily solidify when left in the air are called (ii). Also, fatty oils made solid by adding hydrogen under a nickel catalyst are called (iii), and they serve as raw materials for margarine, etc. When an aqueous sodium hydroxide solution is added to fats and oils and heated, they are saponified to produce (iv) and sodium salts of fatty acids. The sodium salt of a fatty acid is called soap. Because soap has both hydrophilicity and hydrophobicity within its molecule, it has the property of lowering the surface tension of water. A substance that acts like this is called a (v). In water, soap particles arrange their hydrophobic parts on the inside and their hydrophilic parts on the outside to form spherical colloidal particles. Such particles are called (vi). When a small amount of oil is mixed into soapy water and stirred vigorously, the oil is surrounded by soap and disperses into the water. Such an action of soap is called (vii). However, in (viii) with a lot of Ca^{2+} or Mg^{2+}, slightly soluble salts are produced, and the cleaning power decreases.

A. Micelle	B. Hardened oil	C. Drying oil	D. Emulsifying action
E. Surfactant	F. Dispersion	G. Fat	H. Glycerin
I. Ethylene glycol	J. Soft water	K. Hard water	L. Pure water

Challenge Your Thinking

Two oils have the same molecular mass.
Oil A has three C=C bonds.
Oil B has one C=C bond.
Without calculation,
Which has the higher iodine value? .....
Explain .....

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Lesson 4-12 — Aromatic Hydrocarbons

Engaging Introduction

Walk through a city street and you will encounter substances that all have something in common. The fuel used in cars, the plastic parts of electronic devices, the dyes in clothing, many medicines, perfumes, and even aspirin all contain compounds built around the same remarkable molecular structure: the benzene ring.

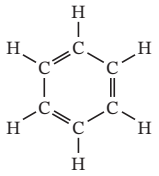
In this lesson, we will explore how the unique structure of aromatic hydrocarbons gives rise to their remarkable stability, reactions, and countless applications in science, technology, and industry.

Guiding Question Why is the benzene ring exceptionally stable, and how does this stability influence its reactions and industrial importance?

Point!

1. Aromatic Hydrocarbons

⟨Structure of benzene⟩

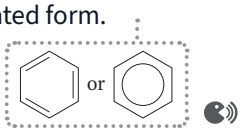


Note: All bonds between carbon atoms are in an intermediate state between a single bond and a double bond.

(a) Benzene: A substance with a structure in which 6 carbon atoms are located at the vertices of a regular hexagon, and one hydrogen atom is bonded to each. The molecular formula is C_6H_6 .

- The regular hexagonal carbon skeleton of benzene is called a benzene ring .
- The structural formula of benzene is often shown in an abbreviated form.

(b) Aromatic hydrocarbons: Hydrocarbons having a benzene ring.



Nature Phenomenon

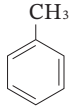
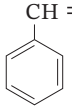
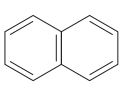
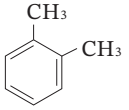
Many plants naturally produce aromatic compounds responsible for their characteristic scents. Examples include:

- Vanilla
- Cinnamon
- Cloves
- Wintergreen

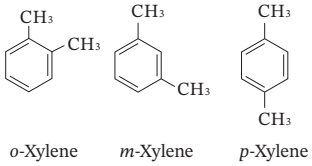
These natural aromatic compounds help plants attract pollinators or defend against insects.

(c) Examples of aromatic hydrocarbons other than benzene

Table 4-12-1 Examples of aromatic hydrocarbons other than benzene

Name	Toluene	Styrene	Naphthalene	o-Xylene
Structural formula				

- When there are 2 substituents on the benzene ring, such as in xylene, there are 3 types of structural isomers: *o*- (ortho-), *m*- (meta-), and *p*- (para-) depending on the positions of the substituents. (Figure 4-12-1 on the right)



o-Xylene *m*-Xylene *p*-Xylene

Figure 4-12-1 Isomers of xylene

Structure of Science

Key Fact :

- Every carbon atom in benzene is sp^2 hybridized.
- All C–C bonds have identical lengths.
- Benzene contains delocalized π electrons.
- Aromatic compounds prefer substitution rather than addition.

Key Concepts:

- Aromatic hydrocarbon
- Benzene ring
- Delocalized electrons
- Aromatic stability
- Substitution reaction
- Addition reaction
- Catalyst

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2. Reactions of Benzene

(a) Substitution reactions • Because the benzene ring is stable, substitution reactions in which hydrogen atoms are replaced by other atoms or groups of atoms readily occur.

(i) Halogenation

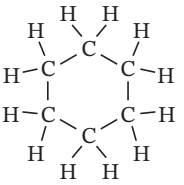
- Chlorination: When chlorine Cl_2 reacts with benzene using iron powder as a catalyst, **chlorobenzene** C_6H_5Cl is produced.
- Bromination: When bromine Br_2 reacts with benzene using iron powder as a catalyst, **bromobenzene** C_6H_5Br is produced.

(ii) Sulfonation: When concentrated sulfuric acid is added to benzene and heated, **benzenesulfonic acid** $C_6H_5SO_3H$ is produced.

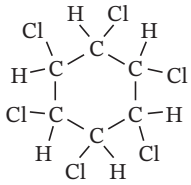
(iii) Nitration: When a mixture of concentrated sulfuric acid and concentrated nitric acid is added to benzene and heated, **nitrobenzene** $C_6H_5NO_2$ is produced.

(b) Addition reactions

- At high-pressure hydrogen H_2 reacts with benzene using nickel or platinum as a catalyst, **cyclohexane** C_6H_{12} is produced.
- When a mixture of benzene and chlorine is irradiated with ultraviolet rays, **1, 2, 3, 4, 5, 6-hexachlorocyclohexane** $C_6H_6Cl_6$ is produced.



Cyclohexane



1, 2, 3, 4, 5, 6-Hexachlorocyclohexane

(c) Oxidation reaction: When benzene is heated to a high temperature and reacted using vanadium(V) oxide V_2O_5 as a catalyst, maleic anhydride is produced.

Life Application

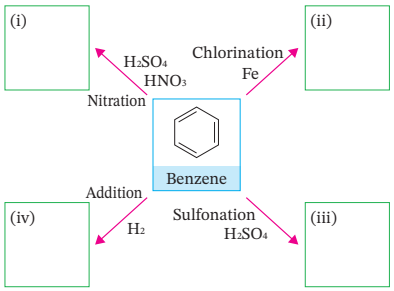
Many medicines—including aspirin, and some antibiotics—contain aromatic rings because their stable structures allow them to interact effectively with biological molecules.

Warm Up

Answer the following questions.

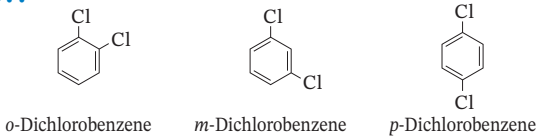
(a) Determine the number of isomers for the aromatic compounds represented by the following molecular formulas. (i) $C_6H_4Cl_2$ (ii) C_8H_{10}

(b) Provide the names and structural formulas corresponding to (i) to (iv) in the following figure.



Explanation

(a) (i)



o-Dichlorobenzene *m*-Dichlorobenzene *p*-Dichlorobenzene

Therefore, there are 3 isomers.

(ii) In addition to the ortho (*o*-), meta (*m*-), and para (*p*-) positions, an isomer having

Be Global Citizen

Aromatic compounds contribute to advances in medicine and technology, but some, such as benzene, are hazardous pollutants. Responsible production and safe handling are essential for protecting both human health and the environment.

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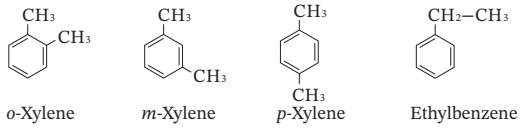
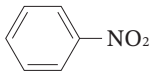
an ethyl group CH_3CH_2- also exists.

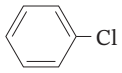


Therefore, there are 4 isomers.

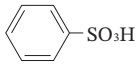
(b) (i) Name: Nitrobenzene
Structural formula:



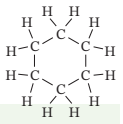
(ii) Name: Chlorobenzene
Structural formula:



(iii) Name: Benzenesulfonic acid
Structural formula:



(iv) Name: Cyclohexane
Structural formula:



Think Critically

A student says:

"Ortho-, meta-, and para-xylene are different compounds.."

Evaluate the Claim

- Is this explanation fully accurate?

.....

- What evidence supports or challenges it?

.....

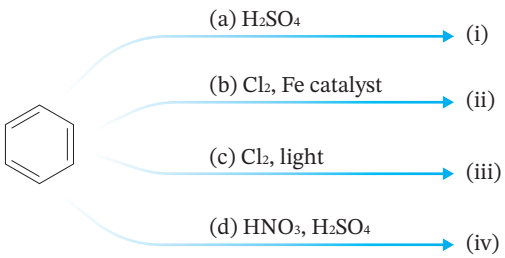
- What is the reasoning that support the evidence?

.....

Try

Choose the correct answer:

1. Which pair represents positional isomers?
   (a) Benzene and cyclohexane
   (b) Ethane and ethene
   (c) Ortho-xylene and para-xylene
   (d) Benzene and toluene
2. Which statement best explains the stability of benzene?
   (a) It contains only single bonds.
   (b) Its π electrons are delocalized around the ring
   (c) It contains triple bonds.
   (d) It has six separate double bonds.
3. Write all the structural formulas of the aromatic compounds represented by the molecular formula $C_6H_4Br_2$.
4. Answer the following questions about the figure below.



(a) Write the structural formulas and names of the compounds corresponding to (i) to (iv) in the figure.

(b) Name the reactions (a) to (d) in the figure.

Sustainability Connection

Modern chemical industries are developing greener catalytic processes that reduce energy consumption and waste during aromatic compound production.

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Exercise

1. Write all the structural formulas of the isomers of the aromatic hydrocarbon represented by the molecular formula C_8H_{10}.

.....

2. Write the names and structural formulas for the organic compounds produced when the following operations **(a)** to **(d)** are performed on benzene. Also, choose the name of the reaction from A to E below and select the appropriate letter.

   (a) React benzene with chlorine using iron powder as a catalyst.

   (b) Add a mixture of concentrated nitric acid and concentrated sulfuric acid and warm.

   (c) React benzene with excess hydrogen using a nickel catalyst.

   (d) Add concentrated sulfuric acid and heat.

.....

.....

A. Halogenation	B. Nitration	C. Sulfonation
D. Oxidation	E. Addition reaction	

Challenge Your Thinking

Investigate common products at home that contain aromatic compounds.
Examples may include:

- perfumes
- detergents
- medicines
- plastics
- food flavorings

Classify each product according to its aromatic compound, if possible.

.....

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Lesson 4-13 — Phenols and Aromatic Carboxylic Acids

Engaging Introduction

Every day, millions of people take medicines to relieve pain, reduce fever, or treat inflammation. One of the most widely used medicines in the world—aspirin—begins its story with a simple aromatic compound called phenol.

Surprisingly, a small change in the structure of phenol transforms it from a corrosive substance into compounds that improve human health and are used in medicine, cosmetics, and industry.

In this lesson, we will explore how phenols and aromatic carboxylic acids demonstrate the powerful relationship between molecular structure, chemical reactions, and real-world applications.

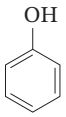
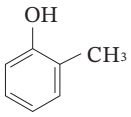
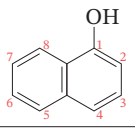
Guiding Question Why do phenols behave differently from alcohols even though both contain a hydroxyl (-OH) group?

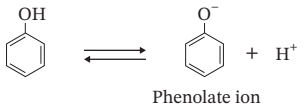
Point!

1. Phenols

(a) **Phenols**: Compounds in which a hydroxyl group − OH is directly bonded to a carbon atom of a benzene ring. (Table 4-13-1 on the right)

⟨Examples of phenols⟩

Name	Phenol	*o*-Cresol	1-Naphthol
Structure			



Phenolate ion

(b) **Phenol and alcohols** Phenol has a hydroxyl group, but it also shows different properties from alcohols.

(i) Similarities to alcohols

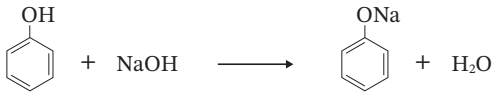
- Reacts with sodium to generate **hydrogen** .
- Reacts with acetic anhydride to produce an **ester** .

Nature Phenomenon

The bark of willow trees naturally contains compounds related to salicylic acid. For centuries, people used willow bark to relieve pain long before scientists understood its chemistry.

(ii) Differences from alcohols

- Partially ionises in an aqueous solution to produce H+, and the aqueous solution shows **weak acidity** .
- Neutralises with an aqueous sodium hydroxide solution to become **sodium phenoxide** .

Example: 

- Shows a purple **colour reaction** when an aqueous iron(III) chloride $FeCl_3$ solution is added.

Structure of Science

Key fact :

- Phenols contain an –OH group directly attached to a benzene ring.
- Phenols are more acidic than alcohols.
- Phenols react with NaOH but alcohols do not.
- Ferric chloride solution identifies phenolic compounds.

Key concepts:

- Phenol
- Aromatic alcohol
- Ferric chloride test
- Aromatic carboxylic acid
- Functional group

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Think Critically

Claim

Phenols are chemically different from alcohols, even though both contain a hydroxyl group.

Evidence

Use at least two observations from the lesson.

1. …… 2. ……

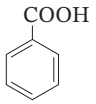
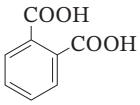
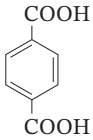
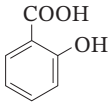
Reasoning

Explain how the presence of the benzene ring changes the behavior of phenols compared with alcohols. ……

2. Aromatic Carboxylic Acids

(a) **Aromatic carboxylic acids**: Compounds in which a carboxyl group − COOH is bonded to a carbon atom of a benzene ring. The aqueous solution shows **weak acidity**.

(b) **Various aromatic carboxylic acids**

Name	Benzoic acid	Phthalic acid	Terephthalic acid	Salicylic acid
Structure				
Manufacturing process	Oxidise **toluene** with an aqueous potassium permanganate solution.	Oxidise ***o*-xylene**.	Oxidise ***p*-xylene**.	Treat **sodium salicylate**, obtained by reacting sodium phenoxide with carbon dioxide, with dilute sulfuric acid.

Think as an Engineer

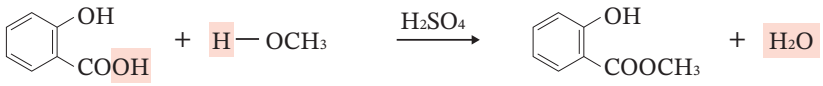
Engineers selecting materials for hospitals or laboratories must consider both chemical effectiveness and safety.

Why is understanding the acidity and reactivity of phenols important when designing disinfectants or antiseptic products?

……

(c) **Reactions of salicylic acid**

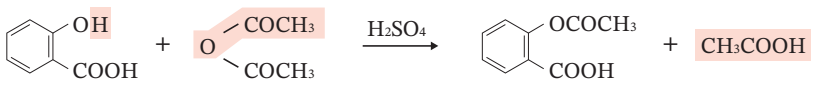
(i) **Methyl salicylate**: Produced when methanol react with salicylic acid in presence of Sulfric acid.



Salicylic acid Methanol Methyl salicylate Water

- Used as an anti-inflammatory analgesic.
- **Shows** a colour reaction with an aqueous iron(III) chloride solution. • Has a phenolic − OH.

(ii) **Acetylsalicylic acid**: Produced when acetic anhydride and concentrated sulfuric acid react with salicylic acid in presence of Sulfric acid.



Salicylic acid Acetic anhydride Acetylsalicylic acid Acetic acid

Note: A reaction introducing an acetyl group CH_3CO- in this way is called **acetylation**.

Misconception Alert

Common Misconception: Because phenol contains a hydroxyl (–OH) group, it behaves exactly like an alcohol.

Reality The benzene ring changes the electronic environment of the hydroxyl group, making phenol weakly acidic and giving it unique reactions, such as reacting with sodium hydroxide and producing a purple color with iron(III) chloride solution.

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• Used as an antipyretic **analgesic**.

• **Does not show** a colour reaction with an aqueous iron(III) chloride solution.

Does not have a phenolic – OH group.

Appreciate Scientists

Scientists transformed the naturally occurring salicylic acid into acetylsalicylic acid (aspirin), reducing stomach irritation while preserving its pain-relieving properties. This discovery became one of the greatest achievements in medicinal chemistry.

Warm Up

Answer the following questions.

(a) For phenol and ethanol, choose all applicable descriptions from A to D below and select the appropriate letters.
(**A**) Reacts with an aqueous sodium hydroxide solution.
(**B**)The aqueous solution is neutral.
(**C**)Shows a colour reaction with an aqueous iron (III) chloride solution.
(**D**) Produces an aldehyde when oxidised.

(b) Write the name and structural formula of the carboxylic acid produced when toluene is oxidised.

(c) Answer the following questions about salicylic acid.
(i) Fill in the blanks (**A**) to (**C**) with the appropriate words in the following text.
Phenol is a substance with (**A**) properties, and dissolves in an aqueous sodium hydroxide solution to form (**B**).
When this reacts with (**C**) under heating and pressure, sodium salicylate is produced, and when it reacts with dilute sulfuric acid, salicylic acid is liberated.

(ii) Write the names and structural formulas of compounds A and B obtained by the following reactions.

$$\text{A} \xleftarrow[\text{Concentrated sulfuric acid}]{\text{Methanol}} \text{Salicylic acid} \xrightarrow[\text{Concentrated sulfuric acid}]{\text{Acetic anhydride}} \text{B}$$

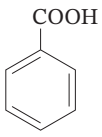
(iii) Which of Compound, A or B, gives a colour reaction with an aqueous iron(III) chloride solution? State the name of the substance and explain the reason for your choice.

Explanation

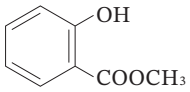
(a) Phenol: Phenol is neutralised by an aqueous solution of a base such as sodium hydroxide to form a salt. Also, when an aqueous iron (III) chloride solution is added, it shows a purple colour reaction. Therefore, A, C.

Ethanol: Ethanol is a primary alcohol, dissolves in water to show neutrality, and becomes an aldehyde when oxidised. Therefore, B, D.

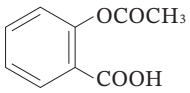
(b) Name: Benzoic acid Structural formula:



(c) (i) A: Weak acid B: Sodium phenoxide C: Carbon dioxide
(ii) A Name: Methyl salicylate Structural formula:



B Name: Acetylsalicylic acid Structural formula:



(iii) The colour reaction with an aqueous iron(III) chloride solution is a test used to detect phenolic compounds (structures in which a hydroxyl group is directly bonded to a benzene ring). Methyl salicylate shows a colour reaction because it

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retains a phenolic hydroxyl group. Acetylsalicylic acid, on the other hand, does not show a colour reaction because the phenolic hydroxyl group of salicylic acid has been acetylated by acetic anhydride, changing it into an ester linkage (– $OCOCH_3$).

Interpreting Data

Study the table comparing phenol and ethanol.

Property	Phenol	Ethanol
Reacts with NaOH	✓	✗
$FeCl_3$ Test	Purple	No colour
Weak acidity	✓	✗

Questions

1. Which compound behaves as a weak acid?
   .....
2. Which observation confirms the presence of a phenolic group?
   .....
3. Explain why both compounds contain –OH but show different chemical behavior.
   .....

Try

1. For the following statements **(a)** to **(f)**, write A if it applies to phenol, B if it applies to ethanol, and C if it applies to both.

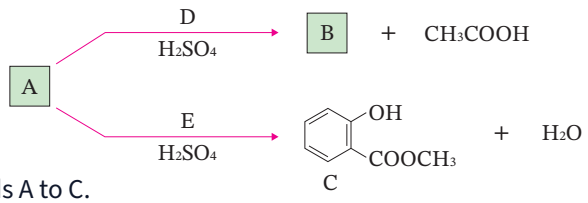
   (a) An aldehyde is produced upon gentle oxidation.
   (b) The aqueous solution shows weak acidity.
   (c) Reacts with an aqueous sodium hydroxide solution to form a salt.
   (d) Shows a purple colour with an aqueous iron (III) chloride solution.
   (e) Highly soluble in water.
   (f) Reacts with sodium to generate hydrogen.

2. Write the name and structural formula of the aromatic carboxylic acid produced when *p*-xylene is oxidised.

3. Read the following text and answer the questions below.

It has been known since ancient times that willow bark has an antipyretic effect, but in the mid-19th century, its active ingredient was found to be compound A. Later, compound B, in which the hydrogen atom of the hydroxyl group of A was substituted with an acetyl group, was synthesised and became the first synthetic drug with antipyretic and analgesic effects. On the other hand, compound C, in which the carboxyl group of A is esterified, is widely used in poultices for muscle pain, etc.

(a) The following figure shows the reaction pathway when synthesising B and C from A. D and E are reagents necessary for the reaction. Write the structural formulas of A and B, referring to the structural formula of C. Also, write the condensed structural formula of E.



(b) Name compounds A to C.

(c) Which of the compounds A to C show a colour reaction when added to an aqueous iron (III) chloride solution? Select all appropriate letters.

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Exercise

Choose the Correct Answer

1.Which compound is used to manufacture aspirin?

(a) Ethanol **(b)** Methanol

(c) Salicylic acid **(d)** Phenol

2. Which reagent is commonly used to identify phenols?

(a) Bromine water **(b)** Sodium chloride

(c) Iron(III) chloride solution **(d)** Hydrochloric acid

3. For the sentences (a) to (c) below, choose all that apply from options A to H, and select the appropriate letters.

(a) Applies to ethanol, but does not apply to phenol.

(b) Applies to phenol, but does not apply to ethanol.

(c) Applies to both ethanol and phenol.

A. Highly soluble in water.

B. Produces an aldehyde when oxidised.

C. Has − OH.

D. The aqueous solution is basic.

E. The aqueous solution is acidic.

F. Reacts with a base to form a salt.

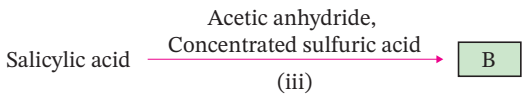
G. Forms an ester.

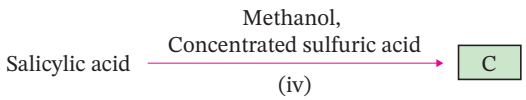
H. Shows a colour reaction with an aqueous iron (III) chloride solution.

4. Read the following text and answer the questions below.

Salicylic acid is synthesised as follows.

Salicylic acid was actively used as a medicine, but because side effects when taken internally became a problem, compound B was developed. Also, compound C, which is used for topical applications, can be obtained from salicylic acid.





(a) Provide the chemical formulas for the substances in (i) and (ii), and name the reactions for (iii) and (iv).

(b) Name the compounds corresponding to A to C.

(c) Write the structural formulas of the compounds suitable for B and C.

Global Challenge

Modern medicine requires effective drugs with minimal side effects. If you were a pharmaceutical chemist, how could you modify the structure of salicylic acid to develop an improved medicine while maintaining its therapeutic effect?

Sketch or describe your idea.

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Lesson 4-14 — Aromatic Amines and Azo Compounds

Engaging Introduction

Imagine wearing a brightly colored shirt, printing with vivid inks, or using a rapid medical test strip. Many of these technologies rely on compounds that were first developed from aniline, a simple aromatic amine.

More than 150 years ago, the accidental discovery of an aniline-based dye revolutionized the textile industry and launched the modern chemical industry. Today, related compounds are used in medicines, plastics, food analysis, medical diagnostics, and advanced materials.

Let's explore how aromatic amines transform into some of the most important compounds in modern chemistry.

Guiding Question

How can one simple molecule lead to colorful dyes, life-saving medicines, and advanced technologies?

Exploration

Look carefully at the following products:

- Colored fabrics
- Printer ink
- Permanent markers
- Medical test strips
- Hair dye
- Laboratory pH indicators

Think:

1. Which of these products depend on organic chemistry? .....
2. Why do some molecules appear brightly colored while others are colorless? .....
3. How might chemists intentionally design molecules with specific colors? .....

Point!

1. Aromatic Amines

(a) Aromatic amines: Compounds in which an amino group $-NH_2$ is directly bonded to a benzene ring.

(b) Aniline $C_6H_5NH_2$

(i) Manufacturing process of aniline: Produced when the nitro group of nitrobenzene is reduced to an amino group.

(ii) Properties of aniline

- A weakly basic liquid.
- Shows a red-purple colour when oxidised with an aqueous bleaching powder solution.
- Poorly soluble in water, but becomes soluble in water when neutralised with

Structure of Science

Key fact :

- Aromatic amines contain an $-NH_2$ group directly attached to a benzene ring.
- The simplest aromatic amine is aniline.
- Aromatic amines behave as weak bases.

Key concepts:

Aromatic amines
amino group

Azo compounds
Diazonium salts
Diazotization
Diazocoupling

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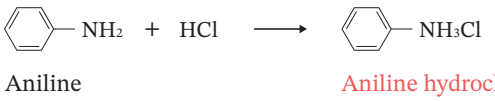
an acid to form a salt.

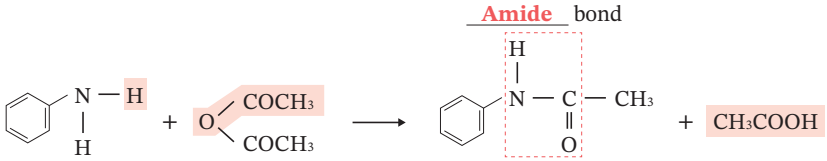
(iii) Reactions of aniline

- When added to hydrochloric acid, it produces **aniline hydrochloride** and dissolves well.



Aniline — Aniline hydrochloride

- When it reacts with acetic anhydride, **acetylation** occurs, and **acetanilide** is produced.



Aniline — Acetic anhydride — Acetanilide — Acetic acid

Inquiry-Based Learning

A chemist wants to manufacture a bright orange textile dye.
Which sequence of reactions would most likely be required?
A. Benzene → Cyclohexane → Ethanol
B. Nitrobenzene → Aniline → Diazonium salt → Azo dye
C. Methane → Ethanol → Acetic acid
Explain your reasoning
……

2. Azo Compounds

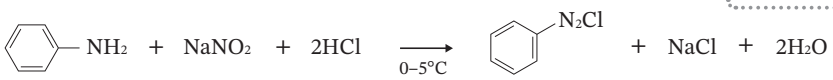
(a) Azo compounds: Compounds having an **azo group** – N = N – in the molecule.

(b) Diazonium salts: Salts having the structure R – $N^+ \equiv N$.

(c) **Diazotization**: A reaction that produces a diazonium salt.

- When aniline is dissolved in hydrochloric acid and mixed with an aqueous sodium nitrite $NaNO_2$ solution, **benzenediazonium chloride** is produced.

Benzenediazonium chloride is a diazonium salt.



Benzenediazonium chloride

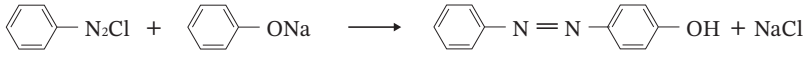
Note: This reaction is carried out under cooling.

〈**Reason**〉 **Because benzenediazonium chloride easily decomposes when the temperature rises.**

(d) **Diazocoupling**: A reaction that produces an azo compound from a diazonium salt.

- When an aqueous sodium phenoxide solution is added to an aqueous benzenediazonium chloride solution, an orange-red ***p*-hydroxyazobenzene** (***p*-phenylazophenol**) is produced.

p-Hydroxyazobenzene is an azo compound.



Benzenediazonium chloride — Sodium phenoxide — *p*-Hydroxyazobenzene (*is an azo compound*)

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Think as an Engineer

An industrial company wants to manufacture aniline safely on a large scale.
As a chemical engineer, suggest:

- methods to control temperature,
- safe storage procedures,
- waste treatment,
- worker protection,
- environmental monitoring.

How would your design reduce industrial risks?

……

Life Application

Aromatic amines are widely used in:

- pharmaceutical manufacturing
- rubber production
- plastics
- antioxidants
- photographic chemicals
- dyes
- agricultural chemicals

Warm Up

Answer the following questions.

(a) When acetic anhydride reacts with aniline, acetanilide is produced. Acetanilide was obtained by reacting aniline with an excess amount of acetic anhydride. Answer the following questions.

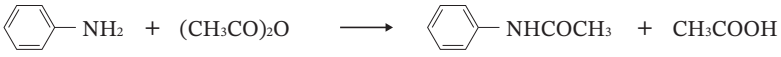
(i) Write a chemical equation for the reaction between aniline and acetic anhydride.

(ii) Acetanilide has an − NH − CO − bond. Name this bond.

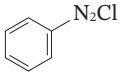
(b) Name the substance produced when an aqueous sodium nitrite $NaNO_2$ solution is added to a dilute hydrochloric acid solution of aniline while cooling with ice, and write its structural formula.

(c) Name the substance produced when benzenediazonium chloride reacts with a mixed aqueous solution of phenol and sodium hydroxide, and write its structural formula.

Explanation

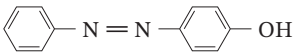
(a) (i) 

(ii) Amide bond

(b) 

(n) When phenol is added to an aqueous sodium hydroxide solution, sodium phenoxide is formed, so it reacts with benzenediazonium chloride.

Name: *p*-Hydroxyazobenzene (*p*-Phenylazophenol)

Structural formula: 

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Interpreting Data

A student measures the stability of benzenediazonium chloride at different temperatures.

Questions

1. Describe the trend? .....
2. Why must diazotization be performed under cooling? .....
3. Predict what would happen if the reaction were performed at 40°C.

.....

Temperature (°C)	Stability
0	Very stable
5	Stable
15	Slowly decomposes
25	Rapid decomposition

Try

Answer the following questions about aniline.

Aniline is obtained when the (A) group of nitrobenzene is (B) to an (C) group using tin and hydrochloric acid. Aniline is a (D) compound and is (E) in water. (i) When hydrochloric acid is added to aniline, it is neutralized to form (F), which is (G) in water. Also, (ii) when aniline reacts with acetic anhydride, it undergoes (H) to produce (I), which contains an (J) bond.

(a) Fill in the blanks with the appropriate words or compound names in the text.

(b) Write a chemical equation for the reaction in the underlined part (i).

(c) Write a chemical equation for the reaction in the underlined part (ii).

(d) Name the compound produced when an aqueous sodium nitrite solution is added to the aqueous solution of underlined part (i) while cooling.

(e) What is the reaction in **(d)** called?

(f) Write the structural formula for the compound produced when an aqueous sodium phenoxide solution is added to the product of **(d)**.

Challenge Your Thinking

Why are azo compounds usually brightly colored while benzene itself is colorless?

Use your understanding of:

- conjugated systems,
- electron delocalization,
- absorption of visible light

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Exercise

Choose the correct answer:

1- Which reaction converts aniline into a diazonium salt?

A. Hydrogenation
B. Diazotization
C. Esterification
D. Hydrolysis

2. The bright color of azo compounds mainly results from

A. ionic bonding
B. conjugated π-electron systems
C. hydrogen bonding
D. saturated carbon chains

Read the following text and answer the questions below:

3. Aniline reacts with acetic anhydride to produce (A), which has an antipyretic effect. This reaction is called the (I) of aniline. Also, after aniline is dissolved in hydrochloric acid, (ii) when an aqueous sodium nitrite solution is added while cooling with ice, (B) is produced. This reaction is called (II). When phenol is dissolved in an aqueous sodium hydroxide solution and added to the aqueous solution of (B), (III) occurs, and an orange-red compound, (C), is produced.

(a) Name the reactions corresponding to the blanks (I) to (III) in the text.

(b) Write the structural formulas for the compounds corresponding to the blanks A to C in the text.

(c) In the molecule of the compound corresponding to blank C, − N = N − exists. Name this functional group.

(d) Write a chemical equation for the reaction in the underlined part (i).

(e) Explain why the reaction in the underlined part (ii) is carried out under cooling.

Grand Challenge

Scientists are trying to replace traditional azo dyes with environmentally friendly alternatives.

Design a new dye that:

- is brightly colored,
- is biodegradable,
- does not release toxic aromatic amines,
- is inexpensive to manufacture.

What chemical properties would your molecule require?

……

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Lesson 4-15 — Separation of Aromatic Compounds

Engaging Introduction

Imagine you are a forensic chemist investigating a suspicious liquid recovered from a laboratory. Analysis shows that it contains four different aromatic compounds mixed together. Before identifying each compound, you must first separate them without changing their chemical structures.

In this lesson, we will explore how chemists use differences in solubility and acid–base properties to separate aromatic compounds efficiently and accurately.

Guiding Question How can chemists separate compounds that look similar but have different chemical properties?

Exploration

A mixture contains:

• Aniline • Phenol • Salicylic acid • Nitrobenzene

Without using chromatography or distillation:

• Which compound would dissolve in dilute hydrochloric acid?.....

• Which would react with sodium hydrogen carbonate?.....

• Which would remain unchanged?.....

• Write your predictions before studying the separation procedure?.....

Point!

Separation of Aromatic Compounds

(a) **Separation experiment**: By using a separating funnel and dividing into an aqueous layer and an organic solvent layer such as diethyl ether (ether layer), compounds can be separated. (Figure 4-15-1 on the right)

• Substances highly soluble in water move to the **aqueous layer** .

• Substances highly soluble in organic solvents move to the **ether layer** .

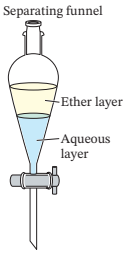

Figure 4-15-1
seperation experiment

(b) **Properties of aromatic compounds**:

Between water and organic solvents, they are highly soluble in **organic solvents** .

(c) **Separation by neutralisation reaction**:

When they become salts through a neutralisation reaction, they become highly soluble in **water** .

• Acids react with a **base** to form a salt.

• Bases react with an **acid** to form a salt.

• Neutral substances do not react with either acids or bases.

Investigation

Research Question.

How does changing the pH affect the solubility of aromatic compounds?

Investigate:

• Which compounds become salts? .....

• Which remain neutral? .....

• Which layer (aqueous or ether) each compound occupies after each treatment?

.....

Construct a separation flowchart based on your observations.

Structure of Science

Key Fact :

• Aromatic compounds generally dissolve better in organic solvents than in water.

• Acid–base reactions can convert neutral molecules into water-soluble salts.

• Separating funnels allow efficient liquid–liquid extraction.

Key Concepts:

• Organic solvents
• Hydrochloric acid
• Neutral substances

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(d) Separation by liberation of weak acids and weak bases:

• A salt of a weak acid reacts with an acid **stronger** than it to liberate the weak acid.

⟨Acid strength⟩

Hydrochloric acid , Sulfuric acid > Sulfonic acids > **Carboxylic acids** > **Carbonic acid** > **Phenols**

• A salt of a weak base reacts with a base **stronger** than it to liberate the weak base.

Aqueous sodium hydroxide solution > **Aniline**

⟨Base strength⟩

Think as an Engineer

A pharmaceutical company must separate valuable organic compounds from industrial waste with minimal environmental impact.

Design a separation process that:

- minimizes solvent use,
- allows solvent recycling,
- reduces chemical waste,
- maximizes product recovery.

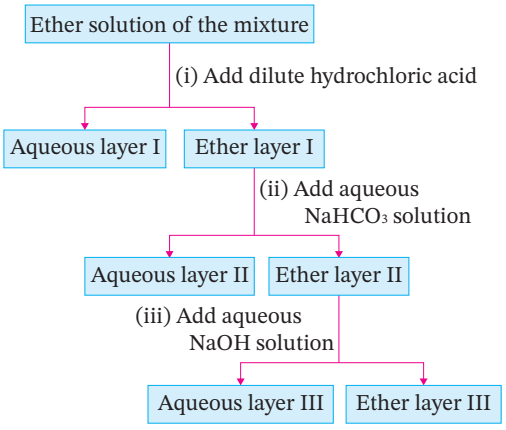
How would your design improve industrial sustainability?

Warm Up

The figure shows the procedure for separating each compound from an ether solution containing a mixture of aniline, salicylic acid, nitrobenzene, and phenol. Answer the following questions.

(a) Write the structural formulas of the aromatic compounds contained in aqueous layers I to III.

(b) Briefly describe the change that occurs when an aqueous sodium hydroxide solution is added to aqueous layer I.

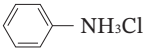


Explanation

(a) Since all 4 substances are aromatic compounds, they are dissolved in the ether solution. Also, their respective properties are: aniline is weakly basic, salicylic acid is weakly acidic, nitrobenzene is neutral, and phenol is weakly acidic.
Verify the reactions in order.

Aqueous layer I: Since the dilute hydrochloric acid added in (i) is strongly acidic, the basic aniline is neutralised to form a salt, which dissolves in water and moves to the aqueous layer. Therefore, aqueous layer I contains aniline hydrochloride.

The structural formula is:



Chemistry in Everyday Life

Extraction techniques similar to those in this lesson are used to:

- isolate caffeine from tea,
- purify medicines,
- remove pollutants from wastewater,
- analyze forensic evidence,
- produce fragrances,
- recover natural products from plants.

Be Global Citizen

Many organic solvents used in extraction are hazardous to human health and the environment. Modern chemistry promotes:

- greener solvents,
- solvent recycling,
- waste reduction,
- safer laboratory practices

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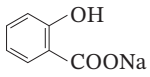
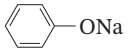
Aqueous layer II: Since the $NaHCO_3$ added in (ii) is a salt of carbonic acid, it reacts with stronger acids. Of salicylic acid and phenol, the acid stronger than carbonic acid is salicylic acid, which is an aromatic carboxylic acid, so salicylic acid becomes a salt and moves to the aqueous layer. Therefore, aqueous layer II contains sodium salicylate.

The structural formula is:



Aqueous layer III: Since the aqueous sodium hydroxide NaOH solution added in (iii) is strongly basic, it neutralises the acidic phenol from the nitrobenzene and phenol remaining in the ether layer to produce a salt. Therefore, aqueous layer III contains sodium phenoxide.

The structural formula is:



(b) When sodium hydroxide, a strong base, is added to aniline hydrochloride, a salt of a weak base, aniline is liberated. ..... Liberation of a weak base

Aniline is liberated.

Interpreting Data

Step	Reagent Added	Compound Removed
I	Dilute HCl	Aniline
II	$NaHCO_3$	Salicylic acid
III	NaOH	Phenol
Remaining	Ether layer	Nitrobenzene

Think Like a Chemist

Questions

1. Why is hydrochloric acid added first?

.....

2. Why doesn't sodium hydrogen carbonate remove phenol?

.....

3. Why is nitrobenzene left in the ether layer?

.....

4. Predict what would happen if NaOH were added first.

.....

Try

Read the following text and answer the questions below.

1. Consider a diethyl ether solution containing dissolved phenol, aniline, salicylic acid, and nitrobenzene.

Operation I: Add 5% aqueous sodium hydrogen carbonate solution and shake well to obtain aqueous layer I and ether layer I.

Operation II: After separating aqueous layer I and ether layer I, add 2 mol/L aqueous sodium hydroxide solution to ether layer I and shake well to obtain aqueous layer II and ether layer II.

Operation III: After separating aqueous layer II and ether layer II, add A to ether layer II and shake well to obtain aqueous layer III and ether layer III.

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(a) Choose one suitable reagent for A from options a to d below.

a. 10% aqueous sodium chloride solution

b. 2 mol/L hydrochloric acid

c. 2 mol/L aqueous sodium hydrogen carbonate solution

d. 0.1 mol/L aqueous sodium hydroxide solution

(b) Write the structural formulas of the organic compound salts dissolved in aqueous layers I to III.

(c) Fill in the blanks (i) to (iv) with the appropriate structural formulas in the following text.

When enough dilute hydrochloric acid was added to aqueous layer I, a white solid (i) precipitated. When enough carbon dioxide was passed through aqueous layer II, (ii) was obtained. When enough an aqueous sodium hydroxide solution was added to aqueous layer III, (iii) was obtained. When ether layer III was evaporated, an oily liquid, (iv), remained.

Exercise

Choose the correct answer:

1. Which compound remains in the ether layer after sodium hydrogen carbonate is added?

(a) Salicylic acid **(b)** Aniline hydrochloride

(c) Nitrobenzene **(d)** Sodium salicylate

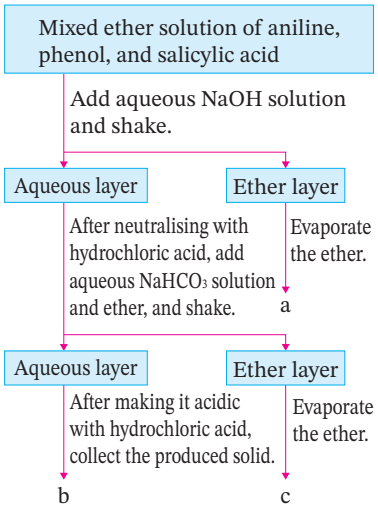
2. Why is sodium hydroxide added after sodium hydrogen carbonate?

(a) It is a stronger oxidizing agent. **(b)** It converts phenol into a soluble salt.

(c) It evaporates the solvent. **(d)** It neutralizes nitrobenzene.

Answer the Following Questions

3. Consider a solution containing aniline, phenol, and salicylic acid dissolved in diethyl ether. Each component of this mixed solution was separated by the operations as shown in the figure on the right. Answer the following questions.


Mixed ether solution of aniline, phenol, and salicylic acid
Add aqueous NaOH solution and shake.
Aqueous layer
Ether layer
After neutralising with hydrochloric acid, add aqueous NaHCO3 solution and ether, and shake.
Evaporate the ether.
a
Aqueous layer
Ether layer
After making it acidic with hydrochloric acid, collect the produced solid.
Evaporate the ether.
b
c

(a) Write the structural formulas for the compounds a to c in the figure.

(b) Choose the reagent that reacts with only one of the compounds a to c from options A to D below, and select the appropriate letter.

A. Fehling's solution

B. Bleaching powder

C. Aqueous iron(III) chloride solution

D .Iodine and aqueous sodium hydroxide solution

(c) If toluene was also contained in the initial mixed solution, where among a to c in the figure would toluene be separated? Select the appropriate letter.

Challenge Your Thinking

Suppose the mixture also contained benzoic acid.

Would the same separation sequence still work?

If not,

Examples may include:

• what would change? • which reagent should be added first?

• why? .....

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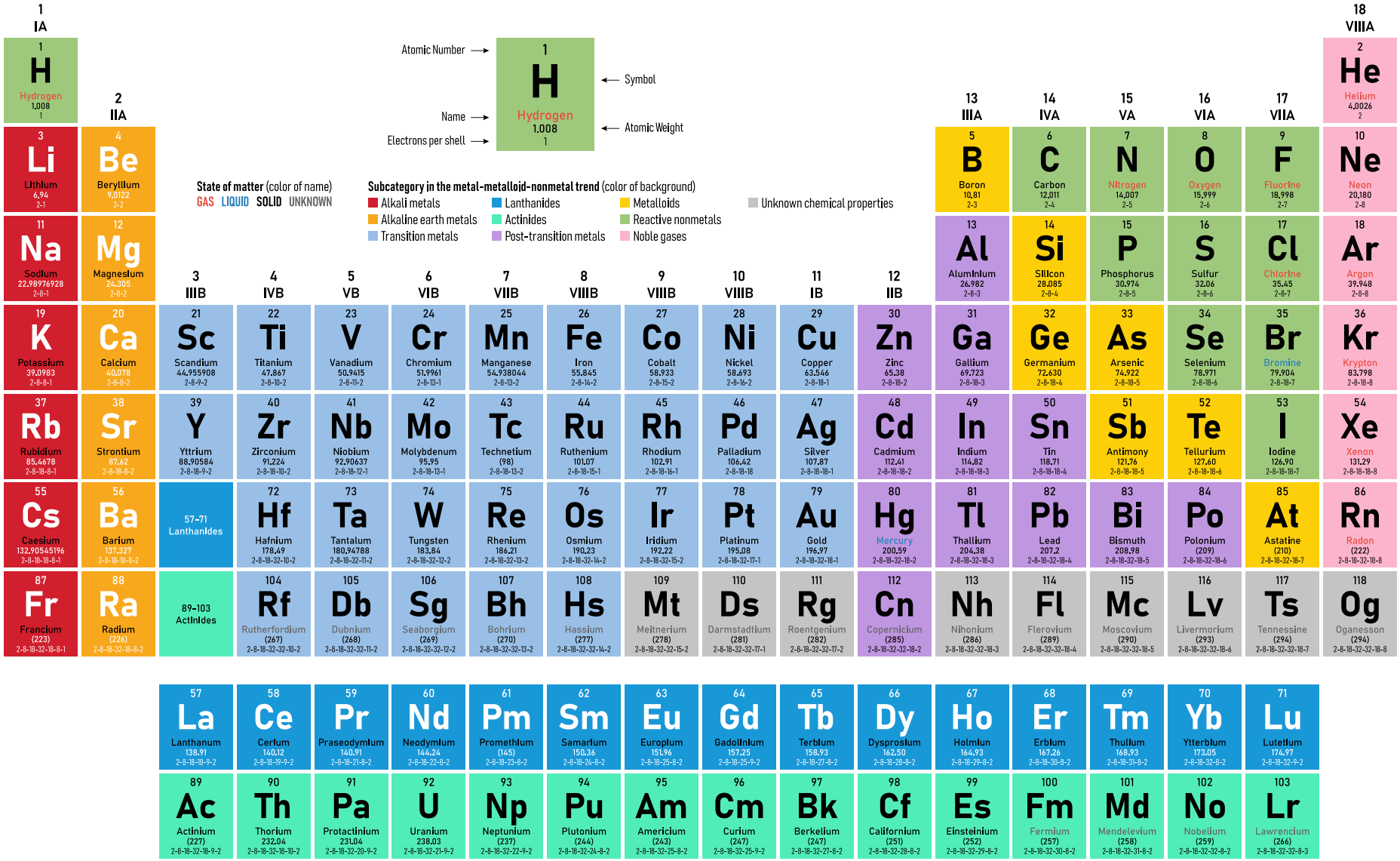
Periodic Table of the Elements



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